Steam Digest

2000

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The Alliance to Save Energy

ALLIANCE TO SAVE ENERGY

20 Years of Leadership

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The Steam Community appreciates every author's contribution to this compendium. Mr. David Jaber of the Alliance to Save Energy is a contributing writer many times over, and he coordinates the publication of his as well as other authors' work. Mr. Ted Jones deserves special mention as the mastermind of the Steam Challenge, which has become BestPractices Steam.

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Introduction

Christopher Russell, Alliance to Save Energy, June 2000

Steam efficiency, and energy efficiency in general, may be the most misunderstood opportunities facing American industry.

While steam is often viewed as an industrial "utility" expense, steam applications are nevertheless the primary consumers of industrial energy. Accordingly, steam presents tremendous opportunities for more efficient fuel consumption, enhanced productivity, improved process reliability, safer workplace conditions, noxious emissions abatement, and—Corporate America please take note—improved financial performance in manufacturing.

This compendium presents the concept of steam efficiency and its multidimensional benefits. These papers were written in 1997-99 by staff involved in U.S. Dept. of Energy's BestPractices Steam program, co-managed by the DOE Office of Industrial Technologies (OIT) and the Alliance to Save Energy. Readers will find a wealth of information about steam efficiency—the parameters of the steam market, the best operational and technical practices for optimizing steam systems, and insight on the measurement and communication of financial benefits provided by steam efficiency.

Steam efficiency was the tool that allowed a Rohm and Haas specialty chemicals plant in Kentucky to improve its net income by a half million dollars. It did so with a steam trap replacement program—in which new traps paid for themselves in an average of 22 days. Steam efficiency also allowed a Georgia Pacific plywood plant to cut its steam requirements by 6,000 lbs./hr. and to reduce CO2 emissions by six percent. The enabling investments—insulation and steam trap upgrades—paid for themselves in six months. The Bethlehem Steel plant in Burns Harbor, Michigan, decreased energy expenditures by $3.3 million, reduced greenhouse gas emissions by 99.7 million tons per year and, at the same time, increased the electricity generation of its on-site turbines. Again, energy efficiency implementation made these results possible.

It is the premise of this volume—and of the BestPractices Steam effort itself—that steam efficiency can be a potential solution to many of the challenges that define the business of manufacturing in the 21st century. Steam efficiency is poised to accomplish or facilitate:

- Containment of operating expenses
- Improved financial performance of operations
- Hedging against sudden price shocks in energy markets
- Greater process productivity and reliability attributable to "BestPractices" in system diagnostics and maintenance
- Improved workplace safety, also through system diagnostics and maintenance
- Emissions control compliance through reduced fuel consumption and energy usage monitoring
- Enhanced corporate image as a responsible member of the community and the environment.

The papers in this compendium give an enlightening overview of the role of industrial steam and the host of benefits that come from its efficient use.

No matter what the degree of a facility manager's motivation, the BestPractices Steam program can be of assistance. The program provides operating tips that can be applied immediately. It offers case studies for modeling more comprehensive upgrade programs. It also provides contacts for training, energy audits, and financing.

Technical information, case studies, tip sheets, diagnostic software, workshop calendars, and training opportunities are all made available through the BestPractices Steam program.

For more information, please contact:

USDOE Office of Industrial
Technologies Resource Room
(202) 586-2090

The BestPractices Clearinghouse
(800) 862-2086
or visit our web site:
http://www.oit.doe.gov/steam

Steam Partnership: Improving Steam System Efficiency Through Marketplace Partnerships

Ted Jones, Alliance to Save Energy, June 9, 1997

Abstract

Steam systems offer many opportunities for cost-effective efficiency improvements. The Alliance to Save Energy, a national nonprofit organization based in Washington, D.C., and the U.S. Department of Energy are working with energy efficiency suppliers to promote the comprehensive upgrade of industrial steam systems. Like EPA's Green Lights and DOE's Motor Challenge, the Steam Partnership program will encourage industrial energy consumers to retrofit their steam plants wherever profitable. The Alliance has organized a "Steam Team" of trade associations, consulting engineering firms, and energy efficiency companies to help develop this public-private initiative.

Overview

In order to put the Steam Partnership program into proper context, this paper is intended to give an overview of steam use in U.S. industry and its importance to our nation's economy. It describes a variety of steam efficiency technologies and practices that can unlock significant efficiency opportunities and help boost industrial productivity and profitability. Finally, it outlines the goals and structure of a new DOE initiative, the Steam Partnership program.

Improving the energy efficiency of industrial steam plants is a significant opportunity for U.S. industry to improve plant productivity and reduce many of the costs associated with production. The Alliance to Save Energy estimates that roughly 2.8 quads (2,800 trillion Btu) of energy could be saved through cost effective energy efficiency improvements in industrial steam systems. The energy savings, worth approximately $6.3 billion (1995 dollars), could be invested in new processes and equipment to improve productivity.

Unfortunately, several factors interfere with the efficient production of steam. First, many boiler operators are not aware of steam system efficiency opportunities and have not been properly trained to look for them. Secondly, industrial plant managers often fail to recognize the importance of the boiler house or appreciate steam's role in the production process. When this happens, boiler operators and maintenance staff soon get the message that efficient operation of the steam system is not a priority.

Finally, operators and managers are rarely aware of steam costs. Too often steam and other utilities (e.g., compressed air and chilled water) are separated from the other factors of production—both physically and in the financial accounting system. As a result steam costs are not assigned to individual processes or production lines. Instead, they are treated as a fixed cost and assumed to be uncontrollable.

Energy-efficient steam systems, like efficient motor and lighting systems, can generate significant savings through reduced fuel consumption. Improving energy efficiency is one of the best and least capital-intensive ways of conserving energy and reducing the amount of pollution that goes up the stack. The Alliance to Save Energy has found no lack of information on specific steam technologies, however, there is little information on steam *system* efficiency. That is why the Alliance, the Department of Energy, and the energy efficiency industry are working to correct this situation through a public-private initiative focusing on steam system efficiency. The goal of this program is to assemble steam efficiency information and provide a delivery system to facilitate industry access and use.

Why Steam Is Important

U.S. industry uses a lot of steam. In 1995, U.S. manufacturers consumed roughly 16.55 quadrillion Btu (quads) of energy for heat, power, and electricity generation [1]. According to the Council of Industrial Boiler Owners, approximately two-thirds of all the fuel burned by these companies is consumed to raise steam, representing approximately 9.34 quadrillion Btu of the 1995 energy total [2].

The U.S. manufacturing economy depends on over 54,000 large boilers to produce steam for process use, to drive mechanical equipment (e.g., pumps and fans), and to generate electricity. It costs U.S. industry approximately $21 billion (1995 dollars) a year to feed these boilers [3].

After the fuels are burned, emissions are released into the atmosphere that cause air pollution and global warming. Each year U.S. industry releases approximately 196 million metric tons of carbon dioxide while producing steam [4]. These emissions represent over 40 percent of all U.S. industrial emissions of carbon dioxide and over 13 percent of total U.S. emissions.

Total demand for steam is projected to increase 20 percent in five major industries by 2015 (compared to 1990 levels), with demand in food processing and chemicals being even greater. Industrial requirements for steam are increasing most rapidly in the "other" category, which includes rubber, plastics, industrial machinery, and transportation equipment (See Figure 1).

The seven industries represented in DOE-OIT's Industries of the Future Program are among the most energy and waste intensive in U.S. industry. When OIT examined the importance of steam in these industries, they found that on a weighted average basis, approximately 45 percent of their total energy consumption was used to raise steam.

The proportion of total energy used for steam was especially high in forest products, chemicals, petroleum refining, and steel (See Figure 2). There is a high degree of overlap between DOE's seven targeted industries and the most steam-intensive industries, which include chemicals, pulp and paper, food and kindred products, and petroleum refining.

Steam Energy Efficiency Potential

Because steam distribution losses can have a significant impact on boiler operations, the efficiencies of boilers and their distribution systems are closely interrelated. For this reason, we have defined the energy efficiency potential for industrial steam systems *as the total of all the cost effective efficiency opportunities in steam generation, distribution, and application, as well as in steam system operation and maintenance*. The Alliance estimates that a total steam system efficiency potential of 30 to 40 percent is available to U.S. industry in three major areas: boilers, steam system operation and maintenance practices, and steam distribution (condensate return) opportunities. (See Table 1).

There is a significant range of operating efficiencies for boilers, depending on the type of fuel, the use of heat recovery equipment, and the operating load. A total steam efficiency potential of 30 to 40 percent appears reasonable when using a systems approach. If all U.S. manufacturers improved the efficiency of their steam systems by even 30 percent they would save approximately 2.8 quadrillion Btu of steam energy—enough to supply the total energy needs of Michigan for a year, generate dollar

FIGURE 2. PERCENT OF TOTAL ENERGY USED BY DOE-OIT FOCUS INDUSTRIES TO PRODUCE STEAM [6]

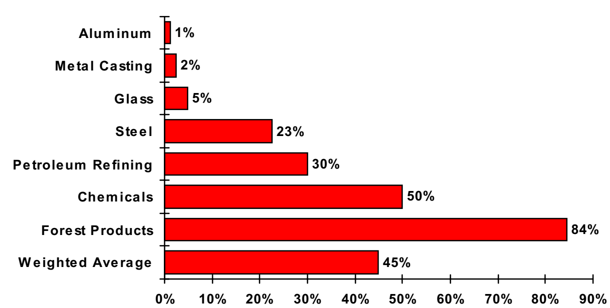

FIGURE 1. GROWTH IN STEAM DEMAND BY INDUSTRIAL SECTOR FROM 1990 TO 2015 [5]

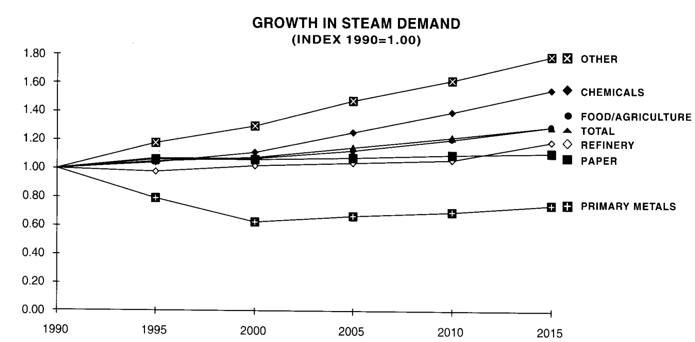

TABLE 1. STEAM SYSTEM EFFICIENCY POTENTIAL

Boilers	***2-5%***
- boiler tune-ups	*1-2%*
- heat recovery equipment	*2-4%*
- emissions monitoring and control	*1-2%*
System Operation and Maintenance	***10-15%***
- water treatment	*10-12%*
- load control	*3-5%*
Distribution System	***15-20%***
- steam leaks and traps	*3-5%*
- condensate return	*10-15%*
- insulation	*5-10%*
Total	***30-40%***

savings of $6.3 billion (1995 dollars), and reduce emissions by 60 million metric tons of carbon dioxide and 30 thousand metric tons of nitrous oxide.

Steam system efficiency is a global opportunity as well, representing an energy savings potential that is five times greater than in the United States alone. Developing countries dedicate a large portion of their scarce energy resources to generate steam. Many of these countries are facing high growth rates and it is uncertain where the energy will come from to meet future demand. If the steam efficiency technologies described here were more widely adopted internationally, energy demand could be reduced by at least 14 quads and carbon dioxide emissions could be reduced by over 250 million metric tons [7].

Achieving Efficiency Gains Through Steam Technologies and Practices

Industrial steam systems contain many cost-effective efficiency opportunities. Each opportunity, by itself, may appear small, improving energy efficiency only a few percentage points. However, the energy savings can add up quickly. Common examples of steam system efficiency opportunities in steam generation, distribution, and operation/maintenance are discussed below.

Opportunities in Steam Generation

Boiler efficiency is the percentage of the fuel's energy which is converted to steam energy. Substantial energy losses are caused by waste heat literally going "up the chimney, " or stack. Therefore, reducing stack losses is probably one of the greatest opportunities to improve steam generation efficiency. Incomplete combustion and heat loss from exterior boiler surfaces can also cause significant losses. Together, these losses can reach 30 percent of the fuel input. The three basic strategies for minimizing stack gas heat loss are:

(1) minimizing excess air in combustion

(2) keeping heat transfer surfaces clean

(3) adding flue gas heat recovery equipment where justified

Assuming boilers are in good repair and properly maintained, the average efficiency of boilers ranges from 76 to 81 percent on natural gas, 78 to 84 percent on oil, and 81 to 85 percent on coal. These efficiency levels can be improved by 2 to 5 percent, on average, with boiler tune-ups and auxiliary equipment where economically justified [8]. Unfortunately, many boilers are not properly operated and maintained. Without proper operation and maintenance practices, fuel handling equipment can get worn, burners and controls can get out of adjustment, boiler water and flue gases are not properly treated, and hot condensate is not recovered. As a result of these conditions steam system efficiency can be significantly reduced. As a rule of thumb, if a boiler has not been maintained for two years, a 20-30 percent gain of efficiency is immediately possible through maintenance [9].

Boiler losses can be reduced with combustion controls and waste heat recovery equipment such as combustion air preheaters and economizers. The economics can be very attractive with boiler efficiency increasing 1.0 percent for each 15 percent reduction in excess air, 1.3 percent reduction in oxygen, or 40°F reduction of stack gas temperature. For new or expanding plants, proper boiler design can have a significant impact on the efficiency of steam utilization as well.

Using emissions monitoring equipment not only helps plant operators track emissions, it can also lower plant energy bills. Researchers from the North Carolina State University evaluated the performance of continuous emissions monitoring systems on industrial boiler efficiency. The monitoring systems reduced excess air by 30 percent (under low fire conditions) and 15 percent (under high fire conditions). These adjustments are projected to reduce stack loss by 1.4 percent. The resulting energy savings were enough to achieve a simple payback of 2.5 years [10].

Opportunities in Maintenance and Operation

There are many opportunities to improve the efficiency of both boilers and the steam distribution system through improved maintenance and operation. A few examples are discussed below.

- **Water Treatment**. Water treatment is an important aspect of boiler operation which can affect efficiency or result in plant damage if neglected. For instance, without proper water treatment, scale can form on boiler tubes, reducing heat transfer and causing a loss of boiler efficiency of as much as 10 to 12 percent [11]. Water treatment represents a substantial portion of overall boiler operating costs. Therefore, improved efficiency throughout the steam system reduces this significant operating cost.

- **Condensate Return.** Recovering hot condensate for reuse as boiler feed water is another important way to improve efficiency of the system. The energy used to heat cold makeup water is a major part of the heat delivered for use by the steam system, requiring an additional 15 to 18 percent of boiler energy for each pound of cold makeup water.
- **Load Controls.** There have been great advances in boiler control technology as older pneumatic and analog electronic control systems have given way to digital, computer-based distributed control systems. These systems are more reliable and can extend boiler life. Modern, multiple burner control, coupled with air trim control can result in fuel savings of 3 to 5 percent [12]. For example, a boiler economic load allocation system optimizes the loading of multiple boilers providing steam to a common header so as to obtain the lowest cost per unit of steam. Honeywell Inc.'s Industrial Automation and Control Division commonly recommends this technology to help customers reduce boiler fuel consumption by 1 to 3 percent and improve performance [13].

Steam Distribution

Taking care of the steam distribution system is often considered to be part of good steam system maintenance. In terms of efficiency, the two do overlap; however, individual steam distribution energy savings can be substantial and merit separate treatment. Steam leaks, steam traps, and insulation are a few of the most rewarding energy efficiency opportunities. On average they can improve a steam system's energy efficiency from 10 to 15 percent. Below are a few examples of steam efficiency opportunities in the distribution system.

- Steam Leaks. A neglected steam distribution system can be very costly. In such systems, leaks will be found in the piping, valves, process equipment, steam traps, flanges, or other connections. Fixing steam leaks is a simple, no cost/low cost opportunity to save energy and money. Steam systems can realize a 3 to 5 percent efficiency improvement when steam leaks are actively identified and repaired.
- Steam Traps. Saving energy through a steam trap maintenance program can seem "too good to be true," yet, the savings are often dramatic. In the absence of a maintenance program, it is common to find 15 to 20 percent of a plant's steam traps to be malfunctioning. Energy efficiency gains of 10 to 15 percent are common when steam traps are actively maintained. Armstrong International estimates that, on average, each defective trap wastes over 400,000 lbs. of steam a year, worth over $2,000 [14]. These savings can add up quickly, especially for plants with many traps. For instance, a typical petrochemical plant will have over 5,000 steam traps, and can save hundreds of thousands of dollars in single year. Savings are also significant for medium-sized plants that often have a few thousand traps, as well as for small plants that commonly have several hundred traps.
- Insulation. A recent analysis estimated the economic conservation potential of thermal-insulation related efficiency to be 5 percent or less of total industrial energy use. However, plants audited under DOE's Industrial Assessment Center program demonstrated a savings potential ranging from 3 percent to as high as 13 percent of total natural gas usage on average [15]. When a Georgia-Pacific plywood plant in Madison, Georgia, upgraded the insulation on the steam lines to its dryers, the plant was able to cut steam usage by approximately 6,000 lbs./hour, eliminate the use of purchased fuel, reduce CO_2 emissions by 6 percent, and achieve a 6-month payback on investment [16].

What Is The Steam Partnership Program?

Although information about specific steam technologies is readily available, there is little public information that addresses the benefits of improving the efficiency of steam plants as a system, including generation, distribution, application, and return. That is why a program is needed to:

(1) improve industrial competitiveness through enhanced productivity and lower production costs

(2) provide steam plant operators with the tools and technical assistance they need to improve the efficiency of their steam plants, and

(3) promote greater awareness of the energy and environmental benefits of efficient steam systems though improved technology and operation.

The Alliance to Save Energy and the Department of Energy's Office of Industrial Technologies are developing a public-private partnership to address the efficiency needs of industrial steam systems. Leading providers of energy efficient steam products and services are working with DOE and the Alliance to develop the program. As envisioned, the program will have three basic components.

How Is The Steam Partnership Structured?

As envisioned, the Steam Partnership program will have three major components - Steam Challenge, Steam Team, and Steam Partners.

Steam Challenge

(ED. Note: "Steam Challenge" has since become "Bestpractices Steam.") This program component consists of a voluntary energy efficiency program targeted to the needs of industrial steam "systems." Rather than promoting the energy savings of any single steam efficiency technology, this program will take a comprehensive approach to promote greater awareness of energy efficiency and pollution prevention opportunities throughout the steam system - from the burner to the boiler, to distribution, to the process, and back to the boiler.

Modeled after DOE's successful Motor Challenge Program, the Steam Partnership program will invite industrial companies to take advantage of the program's technical resources on steam efficiency. In addition, industrial companies will be encouraged to make voluntary commitments to improve their steam plant's efficiency wherever profitable.

Steam Team

(ED. Note: "Steam Team" has since become "Bestpractices Steam Steering Committee.") The Alliance is organizing a "Steam Team" of trade associations and companies from each of the relevant steam efficiency industries to support the steam efficiency program. Today, the Steam Team includes: the Association of Energy Engineers, the North American Insulation Manufacturers Association (NAIMA), the American Gas Association (AGA), the Council of Industrial Boiler Owners (CIBO), Armstrong International, Honeywell Inc., and Spirax-Sarco Engineering. It is anticipated that additional manufacturers (and associations) of other steam-related technologies, such as boilers, water treatment, burners, heat exchangers, diagnostic analysis equipment, pumps, and service providers, such as energy service companies and consulting engineering firms, will also be invited to participate. The Steam Team participants are assisting in developing a plan and undertaking activities to help promote the steam system efficiency concept.

In addition, Steam Team members are contributing materials to be used as educational tools and materials. The goal of this activity is to centralize steam efficiency information that is objective, technically competent, and easy to use. Below are a variety of information tools and activities that the Steam Team is considering:

- Developing a clearinghouse of existing information on individual steam technologies.
- Integrating existing information to promote efficient steam systems.
- Coordinating the use of training and education materials for steam workshops.
- Developing steam efficiency software tools.
- Developing steam system auditing procedures.
- Developing a steam efficiency technical assistance hotline/web page.
- Directory of steam technology suppliers and service providers.
- Producing publications highlighting the potential savings in steam systems.
- Demonstration of energy efficient steam technologies and practices through showcase demonstrations.

Steam Partners

(ED. Note: "Steam Partners" as described here is analagous to the "Allied Partner" initiative advanced by the U.S. DOE's Office of Inductrial

Technologies.") The Alliance plans to involve many organizations servicing the energy needs of industry to help deliver the "steam efficiency" message. These organizations include the Association of Energy Engineers, DOE's Industrial Assessment Centers, state and local manufacturing assistance centers, state energy offices, electric and gas utilities and industry trade associations. Another major deliverer of the Steam Partnership Program would be the marketing and sales staff of the energy efficient product manufacturers participating in the effort.

Centralizing public and private information on steam efficiency and developing tools to match the needs of industrial end-users are important objectives of the Steam Partnership program. Using both public and private resources, the partnership will be able to generate greater awareness of steam efficiency and its economic, energy, and environmental benefits.

Steam Efficiency Resources

As mentioned previously, good information exists on individual steam technologies, but there is little to be found on steam *systems* efficiency. The Alliance to Save Energy has collected some preliminary information on steam efficiency. Below is a brief overview of information resources that are currently available:

- ***North American Insulation Manufacturers Association*** - 3E Plus Software, Georgia Pacific Case Study, study of the energy and efficiency benefits of industrial insulation, industrial insulation fact sheets and brochures, and NAIMA's Commercial and Industrial Operating Committee.
- **American Gas Association** - a variety of publications relating to natural gas technologies, industrial energy use trends, equipment profiles, and AGA's Commercial and Industrial Marketing Committee.
- **Industrial Gas Technology Commercialization Center** - a variety of publications relating to new natural gas technologies in the industrial sector.
- **Council of Industrial Boiler Owners** - a wide variety of publications on environmental emissions, cogeneration, boiler technologies, and alternative fuels, including an upcoming energy efficiency handbook for power plant operators. CIBO has over 65 members representing 19 major industries.
- **Honeywell Inc.** - A *Journal on Industrial Automation* and Control, Honeywell's *Industrial Energy Notes*, case studies, boiler diagnostic software.
- **DOE-OIT:** Information on low emission burners for boilers, industrial heat pumps, process integration using pinch technology, and high performance steam.
- **Armstrong International** - Three worldwide factory seminar facilities, 13 North American sales representative facilities, 4 international sales representative facilities, 8 co-sponsored facilities, 2 mobile seminar vans, extensive library of video tapes, Armstrong Preventive Maintenance software, CD-Rom, *Trap Magazine*, database of steam trap performance.
- **DOE-EPA Climate Wise Program** - provides technical assistance, workshops, seminars, and case studies on energy efficiency to participating companies [17].

Program Activities

On January 16, 1997, the Alliance to Save Energy and the Department of Energy's Office of Industrial Technologies met with representatives from ten key organizations to discuss how the steam partnership program should be structured [18]. The meeting participants strongly supported the steam initiative. Currently, the program is pursuing the following initiatives:

Identify Industry's Greatest Steam Information Needs

The Steam Partnership is conducting focus groups to determine what types of steam efficiency information and services would be most useful to plant operators and most likely to garner the support of industrial decision-makers. Over the next six months, the Alliance and DOE should work closely with industrial steam users through focus groups and roundtable meetings to obtain this information and draft a product development plan based on the results.

Centralize Steam Information

Many of the meeting participants have access to excellent steam information, such as case studies, product descriptions, bibliographies, fact sheets, diagnostic software, product and service provider lists, and education and training materials [19]. The Steam Partnership is in the process of making these resources available to a wider audience by developing a steam efficiency information kit and a dedicated steam efficiency web page.

Develop a Steam Efficiency Diagnostic Tool

Several software tools are now available for individual steam technologies, such as steam traps, insulation, and boiler controls. The Partnership is investigating the possibilities of linking these software tools together and incorporating other steam "modules" (i.e., water treatment, boiler tune-up, common steam applications) in order to estimate comprehensive steam efficiency potential. By incorporating historical data, this steam software tool could also be used to benchmark a particular steam system's relative performance *vis-à-vis* an industry average or BestPractice.

Raise the Visibility of Utility Cost

In terms of cost, it is important for the Steam Partnership to raise the visibility of supplying utilities to the plant. Plant managers sometimes treat energy (which ranges from 3 to 13 percent of production costs) as a fixed cost when, in fact, it is a variable cost that is very much within their control.

Consider Non-Energy Benefits of Efficiency

In addition to energy cost savings, the Steam Partnership should highlight non-energy benefits, or "co-benefits." These benefits include the environmental benefits, worker safety and health, and productivity improvements associated with steam efficiency. Public recognition that comes from participating in a public-private program may also prove compelling to industrial decision-makers.

Conclusion

The Steam Partnership is a unique opportunity to increase industry's awareness of energy efficiency, achieve major energy and cost savings, and improve productivity. Creating a working partnership between the U.S. Department of Energy and the wide range of companies servicing industrial steam systems is critical to the program's success. The three program components (Steam Challenge, Steam Team, and Steam Partners) represent the core activities of the Steam Partnership program. While the program's initial focus is the U.S. industrial sector, there is interest in expanding the program to include other steam-intensive sectors, such as schools, hospitals, municipal district heating systems, the Federal government, and internationally.

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16. Darryl Jackson. 1997. *Case Study: Georgia Pacific Reduces Outside Fuel Costs and Increases Process Efficiency with Insulation Upgrade Program*. Presentation at the Industrial Energy Technology Conference, April 23-24, 1997.

17. In fact, the author is currently collecting information on steam technologies and steam system efficiency opportunities and would appreciate additional contributions.

18. Climate Wise is a voluntary program sponsored by DOE and EPA. Participating companies volunteer to reduce their greenhouse gas emissions by implementing energy efficiency and pollution prevention measures. Climate Wise partners receive public recognition and awards for their achievements.

19. The following organizations participated in the January 16, 1997 Steam Power Partnership Planning meeting: Alliance to Save Energy, American Gas Association, Armstrong International, Council of Industrial Boiler Owners, DOE-EPA's Climate Wise Program, DOE's Office of Industrial Technologies, DOE's Motor Challenge Program, EPA's Office of Policy, Planning and Evaluation, Honeywell, Inc., Lawrence Berkeley National Laboratory, North American Insulation Manufacturers Association, and Plum Street Enterprises. A meeting summary is available from the Alliance to Save Energy, 202-857-0666.

Where Does The Steam Go ?

David Jaber and Ted Jones, Alliance to Save Energy,
February 2, 1999

ABSTRACT

Many associated benefits accrue from plant projects which comprehensively address steam systems. The DOE-Alliance to Save Energy Steam Challenge program was initiated shortly after last year's IETC on April 30, 1998, to promote awareness of these benefits. Program accomplishments include the creation of new steam efficiency tools and software, the opening of a Steam Challenge clearinghouse, and the creation of a Steering Committee and six subcommittees, with several future initiatives in development. Steam energy efficiency opportunities are especially attractive in key industrial sectors.

Emphasizing a "systems" approach to steam efficiency is necessary for optimal operation. This takes into consideration the importance of technologies and practices affecting boilers, distribution systems, steam applications and condensate return. Each of these areas offers energy, pollution, and cost savings, as well important productivity and safety benefits. Particularly important to consider is the interaction effect among these technologies and practices. As an example, poor water treatment can result in early steam trap failure or pipe corrosion down the line. Many examples and case studies bear out the system interactions and the benefits of a systems approach to steam.

IMPROVING COMPETITIVENESS

Many opportunities exist for managers to improve plant productivity, equipment reliability, and financial performance through projects which also save energy. These opportunities are overlooked for a variety of reasons which may include: lack of adequate time for planning; treating utilities as fixed costs; and lack of meaningful dialogue between the executive and plant operator levels. Due to these oversights, industrial facilities often do not realize their true potential in efficient operation.

However, by analyzing the plant as an entire system, the highest priority areas of a facility in resource and energy savings can be identified, and the largest net benefits can be targeted. A "systems perspective" allows plant personnel to step back from the process-specific equipment, and gives direction on which projects warrant the allocation of time and resources. This perspective also helps predict interactions and changes which may occur throughout the plant due to the implementation of a project.

"The essence of . . . systems thinking lies in . . . seeing interrelationships rather than linear cause-effect chains, and seeing processes of change rather than snapshots."

Peter Senge
The Fifth
Discipline

Steam systems in particular benefit from taking a systems perspective. System components to consider are water treatment and combustion in boilers, and the flanges, valves, steam traps, heat recovery, and condensate return of the distribution system. The Alliance to Save Energy has found that a goal of 30% improvement in thermal efficiency is generally attainable in most steam systems. Each component area can offer increased productivity and cost savings as well as benefits related to safety, energy, and pollution reduction through improved maintenance and operation.

Bethlehem Steel

An example of steam efficiency in action is the Bethlehem Steel Burns Harbor Facility. Due to stiff global competition, domestic steel producers have been forced to either improve the efficiency and competitiveness of their steel-making operations or shut down. As this facility had daily electricity, natural gas and potable-water costs of $300,000, management realized that addressing the plant's energy costs could save money and improve the plant's competitive position.

The Burns Harbor Facility has three basic oxygen furnaces (BOFs) capable of producing approximately 300 tons of molten steel in 30 minutes. The steel-making process is electricity-intensive, and Bethlehem Steel generates much of the needed electricity on site using six steam turbines. These turbines are supplied with steam generated in boilers that are primarily fueled with coke oven and blast furnace gases, by-products of the steel-making process. The boilers are also fueled with natural gas when by-product gases are not available. The existing power generation system used treated lake water for boiler feedwater make-up. This water was heated to 240°F using low-pressure steam.

The project entailed redesign of a turbine to increase efficiency, output, and full-load capacity along with allowing the use of excess low-pressure steam in the turbine. This was coupled with changing the source of the boiler feedwater make-up from cool lake water to a warmer condenser cooling water exhaust stream.

Before the turbine upgrade, Bethlehem Steel Corporation (BSC) did not have sufficient generating capacity to consume all of the blast furnace gas during an outage of one of the other turbine generators. This resulted in the by-product gases and their energy being released into the atmosphere, forcing BSC to purchase power and incur substantial demand and energy charges.

Substituting the lake water with condenser cooling water exhaust stream that was 20°F warmer reduced low-pressure steam usage to heat the water. This allowed the excess steam to be injected into the redesigned turbine and increase output. The benefits of the project include [1]:

- Annual cost savings of approximately $3.3 million
- A simple payback of just over one year
- Decreased coke oven and blast-furnace gas emissions
- Reduced high-temperature water discharges into the ship harbor
- Annual electricity savings of approximately 40,000 MWh
- Conservation of 85,000 MMBtu of natural gas each year
- Increase in turbine electrical generation capacity from 42 MW to 48 MW under normal operation, with up to 59 MW possible through use of the excess steam created by the project.

Bethlehem Steel's experience demonstrates that if equipment is scheduled for routine maintenance overhaul, it can pay to go beyond standard maintenance practices. And neither is this limited to Bethlehem Steel; industry-wide, there are similar opportunities. Boiler use in the steel industry comprises 22% of metals sector energy and 3% of total manufacturing sector industrial energy use.

The vast majority of this boiler energy consumption goes into steam production. Steam-use between plants varies widely, depending upon the processing techniques. An example of energy use for a Midwest Steel plant [1]:

Steam Uses	
Mill heating	33%
Processing on the tin line, pickling line[1], galvanizing line, cleaning lines and continuous annealing[2] line	60%
Drip/tracer applications	7%

According to an estimate by RCG/Hagler, Bailly Inc, the growth rates in use of process steam are expected to decline (from 1.7% per 5 year period to about 0.3% by 2000).

Key Industrial Sectors

In addition to steel, the best opportunities for steam projects are among other energy-intensive heavy manufacturing industries, such as:

- Pulp and Paper
- Petroleum
- Chemicals
- Food Processing
- Textiles

The only energy-intensive industries not represented are the highly electricity-dependent exceptions, such as aluminum refining, and those less dependent on low and medium range heating, such as glass.

Pulp and Paper

Pulp and paper facilities include those plants which process biomass into pulp, and use it as a feedstock to produce paper and paperboard.

Statistics

Approximately **82 percent** of total pulp and paper manufacturing energy is used for steam production [2]. This represents 13% of all manufacturing industrial energy consumed.

[1]Pickling is the process of cleaning the strip of steel to remove oxides from its surface.
[2]Annealing is the term given to the process of heating and cooling coils of steel in a controlled atmosphere to soften them.

24% of steam used in pulping
20% of steam used for bleaching
41% of steam used for papermaking [3]

Processes

The entire manufacturing process requires large quantities of relatively low pressure steam. High pressure steam is used for electricity generation. Exhaust steam from the electricity-generating turbines is used in:

Pulping: Approximately 94% of pulp for papermaking is produced from wood, which is soaked and prepared into pulp using steam dryers [4]. Pulping processes are generally divided into chemical, mechanical, or a combination. Chemical processing is the most steam intensive [5].

Bleaching: About a half of chemical and chemical-mechanical pulp gets bleached [6]. Steam is required for heat and mechanical drives for equipment, such as washers, showers, and vacuum pumps [7].

Papermaking: The five basic steps in the papermaking process are: stock preparation, web formation, pressing, drying, and finishing [8]. Steam is used in each process, with drying the most steam-intensive. During the drying process, the wet sheet of paper is run through a press roll that is heated to between 250° and 375°C. As the sheet is going through the press roll, steam is generated in the sheet that expels excess water [9].

Petroleum

The petroleum sector includes industries which refine crude oil to produce hydrocarbon fuels, lubricants and coal products.

Statistics

28 percent of total energy, representing 6% of total manufacturing energy, is used for steam production in petroleum refining. The refining process uses large quantities of low-pressure steam, primarily as an energy source to break down crude oil and process it into usable fossil fuel products [10].

Processes

Distillation: Distillation involves heating crude oil into various boiling ranges so that it can be separated into gasoline, fuel oils, lubricants and other products. The two main methods of distillation are atmospheric and vacuum distillation. Steam provides 22% of total atmospheric distillation energy use and 44% of vacuum distillation energy [11].

Coking: Coking converts heavy residual stocks into gas, distillates, and coke with the intention to maximize yield in distillates, and minimize yield in gas. Depending on the coking method, steam may be created in this process.

Desulfurization: Hydrodesulfurization (HDS), also referred to as hydrorefining, reduces sulfur content in preparation for further refining. Steam supplies roughly 28% of total energy for steam in HDS of naphtha and distillates, and about 18% for gas oil [12].

Alkylation: Steam is a major energy source in the butane isomerization process, which changes the hydrocarbon molecular structure to ensure enough isobutane is present for alkylation. Steam meets 79% of total energy needs in alkylation [13].

Hydrogen Production: Hydrogen production can be required to supplement the surplus hydrogen produced from catalytic reforming. In this process, steam reforming is the common practice to produce hydrogen commercially [14].

Chemicals

Facilities which synthetically produce rubber, plastics and resins, gases, fibers, fertilizers, and inorganic and organic compounds are included in the chemical sector.

Statistics

52% of total energy in the chemicals industry is used for steam production, representing **10% of total U.S. manufacturing energy use.** The boiler production capacity in chemicals is the highest for any single industry both in number of boilers and total capacity.

Processes

Steam accomplishes many functions, most prominently:

Machine Drive: Along with electric motors and gas turbines, steam turbines are often used for the purposes of pumping, compression and motive force.

Reactors: Often reactors are heated by steam, usually “waste” steam from other industrial practices.

Direct Use: Steam is utilized for such activities as stripping, reforming, and as a feedstock.

Low Temperature Fire Heaters: Furnaces which do not require temperatures above 800°F are often heated with steam.

Electricity Generation [15]

Outlook

Current consumption trends predict a 4.3% average annual growth rate (between the years 1985 and 2010) in demand for process steam. However, exploration and implementation of energy conservation methods, process modification, integration and expansion of electrification could reduce that rate to approximately 2% per year.

Food Processing

Food processors prepare a wide variety of fruits, vegetables, and animal products into purchasable products. Prominent among these are grain millers, dairies, breweries and distilleries, and vegetable oil manufacturers.

Statistics

Energy for boilers comprises an estimated **56% of food industry** energy use and **4% of total manufacturing energy use** [16]. Process steam contributes significantly to energy requirements in many food sectors, including [17]:

Sector	% energy
Poultry/egg processing	23
Wet corn milling	31
Candy/chewing gum	41
Soybean oil mills	20
Malt beverages	43
Distilled/blended liquors	40

Plants rarely generate their own electricity with steam—steam is generated for process use. Exceptions to this are breweries, which commonly cogenerate electricity with extraction steam turbines.

Compared with other manufacturing industries, food processing utilizes a proportionally greater quantity of smaller boilers. Food processing must utilize heat exchangers instead of direct contact between the food and the steam (for health purposes), and feedwater chemicals must be non-caustic to prevent contamination in case of leaks.

Processes

Numbered among major end applications for steam are cooking, sterilization, blanching, pasteurization, and dehydration of food products. Like the food processing sectors, each application provides unique opportunities for improvement. For example, in blanching, which is a process to inactivate enzymes and bacteria to preserve food products, major efficiency problems include generation of large quantities of waste water and inefficient use of energy due to heat loss/poor insulation of steam systems [18].

Outlook

Based on current consumption and the assumption of static technology, the food industry is expected to generate an average annual growth in its process steam of 2.6% until the year 2010. This would increase steam demand from 737 to 1209 trillion Btu between 1985 and 2010. If the industry pursues more efficient practices, such as electrification and process integration, there exists the potential to decrease the average annual growth rate to 0.2% [19].

Textiles

Textile mills take raw cotton, wool, and other plant and animal fibers and refine them for use by apparel, rug, and upholstery manufacturers.

Statistics

Boiler use accounted for 148 trillion Btu in 1985, which was **35% of total energy use** [20].

Processes

Textile drying accounts for a significant portion of steam use, with wet processes accounting for approximately 60% of energy consumption [21].

Outlook

Process modifications which could affect steam demand include continued shift to dry processing from wet processing, continued reductions of wet process water content, and use of energy-saving technologies such as indirect steam dye heating and foam finishing. Steam demand is expected to decrease approximately 5% every five years. Combined with process modifications, industry growth, and electrification, this results in a projected annual growth rate of –0.3% in net steam use [22].

Steam Challenge

Due to the high use of steam, those responsible for plants in these industries stand to gain handsomely by ensuring their steam systems are operating as optimally as possible. However, realizing the opportunities requires having the direction, the proper information, and the resources. The Alliance to Save Energy, the Department of Energy's Office of Industrial Technologies (DOE-OIT), and industry leaders are providing this direction, information and resources through Steam Challenge. Steam Challenge emphasizes a systems approach to steam efficiency in all these industries, taking into consideration the importance of technologies and practices affecting boilers, distribution systems, steam applications and condensate return. Systems areas include:

- Water treatment
- Boilers
- Controls
- Heat recovery
- Training
- Maintenance
- Traps and leaks
- Insulation
- Auxiliaries
- Flue gas treatment
- Cogeneration
- Co-firing
- Trouble shooting
- Combustion.

Numbered among Steam Challenge activities are communicating steam project benefits, developing unbiased resources for steam system operators, and providing access to training opportunities.

Optimization of industrial steam systems represents one of the largest non-process, industrial energy opportunities, with improvements of 30-40% readily achievable through the introduction of a BestPractice approach. However, lack of information has been a primary barrier to realizing substantial improvements in efficiency, reliability, productivity, and safety. Steam accounts for $21 billion per year of U.S. manufacturing energy costs and 196 million metric tons of carbon equivalent (MMTCE), representing 13 percent of total U.S. emissions and 40 percent of U.S. industrial emissions. Steam Challenge expects to achieve an overall efficiency improvement of 20% by the year 2010.

Steam is used to heat raw materials and treat semi-finished product at a constant temperature. It is also a source of power for prime movers and equipment as well as building heat and electricity generation. Over 33,000 large boilers are used to produce steam by U.S. industry. Total demand for steam is projected to increase 20 percent in five major industries between 1990 and 2015.

Several hundred representatives of these energy-intensive industries and distributed heating systems have expressed interest in Steam Challenge to save their companies' steam, product, and money. A novel program development has been its close interaction with private industry and the valuable input industry has been able to provide. Thirty-two companies and organizations are actively participating in the development of the program (See Table 1).

Communications

With the Bethlehem Steel project, although the **application** was the original point of investigation (energy costs in turbine operation), it led to investigation of the **steam system** as a whole. Successes such as these need to be communicated to upper-level facility management to incorporate the benefits of comprehensive energy-efficiency projects into the selection and finance allocation process.

However, this has not been happening in the marketplace. A major barrier to implementing system enhancement projects is the situation where upper-level management is not aware of the opportunities of more effective energy management, even if plant engineers have the technical information. The benefits of projects and technologies are often presented as reducing costs or merely being more energy-efficient. With energy prices at historic lows, this must be translated into the language of internal rate of return, return on investment, and other figures company decision-makers need to authorize a project.

Broadcasting the message to a broad audience has been a key program focus. Information on steam efficiency opportunities are available at the Steam Challenge web site (www.oit.doe.gov/steam). Steam Challenge has conducted steam efficiency sessions at conferences, and presentations at trade shows, private meetings and seminars. Presentations draw on the experiences of industry associations, suppliers, and organizations regarding steam systems.

Approximately 70 energy managers from a variety of industrial, institutional, and government facilities have been given briefings on the program through the efforts of steam system equipment suppliers and associations supporting Steam Challenge, including Swagelok and the

TABLE 1: PARTICIPATING ORGANIZATIONS

American Boiler Manufacturers Association (ABMA)
Institute of Textile Technology
American Gas Association
International District Energy Association
Armstrong International, Inc.
Iowa Energy Center
BASF Corporation
Knauf Fiberglass
Bethlehem Steel Corporation
NAIMA
Construction Engineering Research Laboratory—U.S. Army Corps of Engineers
NALCO Chemical
Coors Brewing Co.
National Board of Boiler and Pressure Vessel Inspectors
Council of Industrial Boiler Owners
National Insulation Association
Coors Brewing Co.
NYSERDA
Duke Solutions
Rock Wool Manufacturing
DuPont
Rohm Haas
Energy Center of Wisconsin
Spirax Sarco Inc.
EPRI
Swagelok Inc.
Gas Research Institute
Technical Association of the Pulp and Paper Industry
Georgia-Pacific
Trigen
GESTRA
Utah Steam Technology Coalition
Honeywell Inc.
Yarway Corp.
Industrial Assessment Center

American Gas Association. Spirax-Sarco and Armstrong International have played key roles in advertising training seminars. Several associations have also sponsored briefings for their own members. Among these are the National Insulation Association, the American Boiler Manufacturers Association, the Technical Association of the Pulp and Paper Industry and the Council of Industrial Boiler Operators.

A Clearinghouse was also established to provide a central location for technical resources and program information. The Clearinghouse is operated by the Washington State University's (WSU) Cooperative Extension Energy Program, where access to technical help and steam resources is available via a fax line, mailing address, e-mail line and the Steam and Motor Challenge Hotline. The clearinghouse will have technical experts on staff to answer most steam-related questions and access to outside steam experts for more detailed questions. Interested plant personnel now have a streamlined process to obtain the steam resources they need.

In its first two months of operation, the Steam Challenge Clearinghouse fielded over 100 inquiries from interested callers. Callers receive a list of additional area-specific documents and resources offered through the Clearinghouse.

To contact the Clearinghouse:
E-mail: steamline@energy.wsu.edu
Phone: (800) 862-2086
Fax: (360) 586-8303
Address: P.O. Box 43171
925 Plum St. SE
Olympia, WA 98504-3171

Training

Three pilot training seminars were conducted in 1998. About a total of 180 attendees learned about boiler fundamentals and suggested practices regarding combustion, water treatment, flue gas, steam traps and steam distribution throughout the course of the day. Training was conducted in concert with Virginia Polytechnic's Energy Management Institute.

The goal was to assemble training materials and curricula of proven value to steam system operators. Feedback from attendees will be used to critique the presented materials and target the training style and information which attendees found most helpful. The findings will eventually be made available to trainers and consultants involved with steam systems.

Resources

At last year's Industrial Energy Technology Conference, initatives announced for Steam Challenge included: working with the Council of Industrial Boiler Owners (CIBO) to publish the *Energy Efficiency Guidebook* for boilerhouse operators and assembling tools from various associations and trade groups, such as North American Insulation Manufacturers Association's (NAIMA's) 3E Plus insulation software and Oak Ridge National Laboratory's Industrial Insulation Guidelines.

All of these materials are now available through the Clearinghouse. The complete list of Steam Challenge materials to date includes:

- DOE-OIT Steam Challenge brochure
- 1998 Industrial Energy Technology Conference Steam Session Papers (10)
- Council of Industrial Boiler Owners Energy Efficiency Handbook for Powerhouse Operators
- September 1998 Plant Services magazine, "*The Steam Challenge*"
- September 1998 Energy Manager article, "*Steaming Ahead* "
- 3-E Plus Insulation Softwre to determine optimal insulation thickness
- Oak Ridge National Laboratory Insulation Guidelines
- Bethlehem Steel case study
- Georgia Pacific case study
- May 1998 Fortune magazine, "*Turn Down the Energy, Tune Up the Profits*"

Collecting unbiased technical documents is an ongoing effort. Case studies are a compelling way to show achievements in real facilities and verify steam and energy efficiency opportunities.

Anyone interested may submit projects to be considered for case study development. Companies which submit projects have the final judgment on publishing the case study. In exchange for releasing their data, the company receives recognition for their efforts and has their work publicized as an example of what similar companies might achieve.

Projects which do not have sufficient data for a case study, but still demonstrate steam system-enhancement benefits, will be developed into success stories. Related to this effort is the establishing of benchmarks for steam systems and BestPractice procedures, which will provide direction on how to operate in a particular facility.

Again, the focus is on steam systems because that is an area of opportunity. However, the real concerns of end-users of steam are what we hope we address. These are concerns such as enhancing the competitiveness of their businesses and using their assets as productively as possible. To maximize its usefulness to the end-user, Steam Challenge acts as a gateway to research, advanced technology, technical assistance, and financing programs offered by DOE-OIT. This goes beyond steam systems to a vast array of services for entire facilities to look at the entire manufacturing picture.

To the Future

Many more companies are anticipated to become involved with Steam Challenge as case studies are developed and draft technical documents, marketing tools, BestPractice guidelines, and training curricula become ready for review. The companies and organizations who help direct the program are currently determining which specific initiatives to pursue and their priority. Our initiatives will include:

1. Training Options

- Compile a comprehensive list of consultants and organizations already providing training.
- Determine minimum standards for system training, with possible certification.

2. Technical Tools

Steam Challenge is assessing already-existing case studies which have been developed by equipment and service providers, the Department of Energy, utilities and other organizations. These are being categorized by industry sector, industrial process application, and equipment type to make information easily accessible to those interested in particular areas.

A "best-resource" list for steam generation, distribution, recovery, and end use application has also been collected. This includes texts, worksheets, standards and guidelines, and software. Several computer software tools are commercially available which address components of a steam system. The following modeling tools focus on boiler performance, distribution systems, steam traps, insulation optimization or process heat loads, but could potentially be assembled into a software package modeling an entire steam system.

- HEATMAP – evaluates district heating and cooling system performance
- Steam$$ – models distribution systems, calculating costs for energy losses and trap management
- Visual Mesa – helps optimize petrochemical processing
- Honeywell boiler assessment tool – calculates cost/Btu of steam generation
- 3E+ – optimizes insulation thickness
- Trapbase – management system for steam traps

3. Benchmarks and BestPractices

Investigation is underway for developing a baseline on current steam use throughout industry and on the plant level to allow firms to assess how they are performing and track change. A similar effort has been conducted for energy use in the United Kingdom. The UK's Dept. of the Environment's Energy Efficiency BestPractice Program (UK EEBPP) is primarily a knowledge-based information transfer program designed to assist energy users in the industrial, commercial, and transport sectors. The UK program has collected and developed a considerable amount of steam efficiency information in the form of BestPractices guides, case studies, and benchmarking guides.

Of particular interest was their development of a carefully targeted marketing program with impact assessment studies to determine their program's 5-year performance. These studies measured energy use at fixed sites in an industrial sector at the start of their program and after five years to determine the amount of improvement. A collaborative effort with the UK EEBPP to recreate this work in the United States will be pursued.

4. Marketing

Steam Challenge is committed to make the case for project implementation more compelling by demonstrating the associated productivity, reliability, and safety benefits and translating this into dollars for a more realistic and effective argument to consider steam system projects. Further targeting of the audience will be done to help ensure projects are assessed and completed. Articles will be drafted for magazines and literature outside of the trade press, possibly including *Fortune*, the *New York Times*, *Black Enterprise*, and the *Harvard Business Review.*

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Steam Efficiency: Impacts From Boilers To The Boardroom

Christopher Russell, Alliance to Save Energy, September 15, 1999

Abstract

Historically, energy utilization may have received corporate industries' attention only because of fuel price shocks or regulations imposed on the industry. That history obscures the potential value that energy efficiency can convey to the manufacturer's bottom-line financial position. The challenge is to present efficiency investments in the financial "language" that permits comparison to other corporate investment opportunities. This paper presents a framework for linking steam efficiency to financial goals. A systematic review of business forces acting upon the manufacturing firm reveals the financial benefits derived from applied steam efficiency. Primary benefits are related to savings in the production process and its energy inputs. Secondary impacts potentially include increased working capital, market branding opportunities, positioning for merger and acquisition events, avoidance of emission control penalties, improvements in workplace safety, and reductions in hazard insurance premiums. Several numerical examples are provided in the text to illustrate the application of key financial variables. The final discussion here covers the U.S. Department of Energy's BestPractices Steam program, which develops and communicates the technical resources that can help industrial operators to optimize their steam system performance.

Introduction

Steam efficiency is an under-appreciated source of potential operating income for manufacturers. Scarce capital and limited staff time are common explanations for corporate inattention to energy-efficient practices in manufacturing (Pye, 1998). Historically, many facility managers have thought of "energy efficiency" as a form of regulation that complicates their business and potentially costs money. This view ignores the fact that energy-efficiency practices have the potential to reduce a variety of expenditures and in some circumstances may even *increase revenue.* Either way, efficiency measures can produce savings that may be applied to other corporate priorities.

Falling energy prices throughout the 1990s have generally decreased the urgency to contain industrial fuel consumption. In addition, production assets in many industries become increasingly obsolete as firms are forced by competitive pressures to invest in new plant and equipment. Some firms are hesitant to invest in energy efficiency when asset managers assume that these investments take too long to pay for themselves through energy savings. Other firms are simply under pressure to divert earnings into short-term shareholder returns.

To some corporate observers, industrial steam systems initially seem to offer few opportunities for lowering overall production expenses. The boardroom may see steam as an indirect production element, and therefore discount steam efficiency relative to direct production process investments. Accordingly, other production managers may be better able to justify and compete for scarce investment funds in the firm's capital budgeting process. The steam facility manager is especially at a disadvantage when his or her requests for capital are not presented in the financial "language" that corporate officers will most appreciate.

An important part of implementing steam efficiency programs is the appropriate use of financing tools. Options include bank loans and commercial paper, bonds, stocks, use of retained earnings (or "working capital"), capital leases, true leases, and performance contracts. Discussion of these options is beyond the scope of this paper, but Woodroof and Turner (1998) is a highly recommended reference for demonstrating each example.

The balance of this paper will illustrate the financial impact of steam efficiency through a variety of quantitative measures. The financials for a fictional company, ABC Manufacturing, are presented as an ongoing case study throughout the text. While the company and the data are imaginary, the financials were created to reflect realistic manufacturing operating results.

Making "Business Sense" of Steam

Overview

If manufacturers see steam as a fixed cost of production, then steam expenses may simply be summarized as a line item on an income statement. This view ignores the business forces acting upon the firm—forces that can either raise the cost of doing business, or perhaps serve as opportunities to lower expenses and improve operating incomes. When promoting steam efficiency to a corporate audience, it is necessary to spell out the anticipated benefits in annualized dollar impacts. For example, one year's savings in energy expense should be expressed as a contribution to annual operating income.

The steam facility manager's dialog with the corporate office should recognize corporate priorities and the ways in which facility management can respond to those challenges. That dialog should explain how **steam operations** potentially engage a number of **business forces** within and beyond the industrial firm. The movement of business forces impacts current **issues at-risk**. In turn, the issues at-risk each have direct implications for corporate performance, as monitored through a number of **financial variables**. Steam efficiency will be better appreciated in the boardroom once the linkages from steam operations to corporate performance are demonstrated. These concepts, depicted in Figure 1, are discussed in detail in the following text.

Figure 1: Business Forces, Issues At-Risk, and Financial Variables

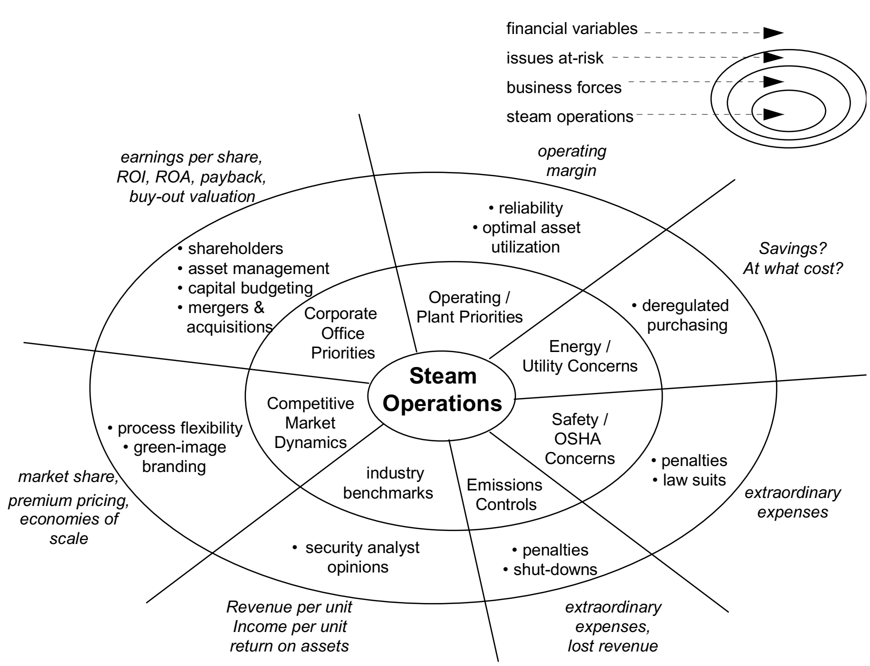
Impacted by Industrial Steam Efficiency.

Steam Operations

Steam is a significant source of process heat and power generation throughout manufacturing, and especially in the production of foodstuffs, textiles, pulp and paper, chemicals, refined petroleum goods, and primary metal products. To the extent that national resource management policies depend on efficient energy utilization, industrial steam efficiency obviously deserves policy attention. Steam accounted for approximately $25 billion of total manufacturing costs in 1995 (U.S. DOE/EIA, 1997). The volume of energy utilized in steam production ensures that there are many opportunities for monitoring and improving efficiency practices. Also, this suggests that steam *should* be a target for expense reduction within manufacturing industries. Finally, the need for "steam solutions" is a growth opportunity for manufacturers or providers of insulation, distribution hardware, instrument controls, and energy management services.

STEAM EFFICIENCY. The best steam efficiency opportunities are incorporated into industrial facilities in the planning stages. Still, ongoing

FIGURE 1: BUSINESS FORCES, ISSUES AT-RISK, AND FINANCIAL VARIABLES IMPACTED BY INDUSTRIAL STEAM EFFICIENCY



maintenance pays dividends in the form of operating cost containment. To provide perspective, a simple boiler tune-up can yield a 0.2 to 0.9% increase in steam efficiency (Payne & Thompson, 1996). This effort involves the optimization of air and fuel combustion mixtures and is a quick and virtually cost-free process. In general, corporate decision-makers should realize that diligent steam system maintenance is a consistent and predictable expense, while the costs associated with poor maintenance are unpredictable and potentially catastrophic.

A corporate audience should appreciate the four fundamental areas of opportunity for steam efficiency. These are *generation*, *distribution*, *end-use*, and *recovery*.

Generation refers to steam production in a boiler vessel. The primary task here for steam operators is to balance system reliability with fuel combustion, emissions release, and thermal loss. Proper burner design, maintenance, and system monitoring allow the steam operator to optimize combustion—with direct impacts on system reliability and fuel consumption.

Distribution entails the routing of steam from its origin to application points in the production process. Steam application usually demands a variety of pressures throughout one system. This in turn depends on the use of pressure-regulating valves, meters, steam traps, and interconnecting pipes. Leaks are an unavoidable consequence of utilizing such hardware, but their frequency and impact can be minimized through maintenance routines. Leaks can be expressed as a negative cash flow, since additional inputs are required to make up for steam losses. Clearly, quality hardware pays for itself in terms of leak prevention. Similarly, heat loss that simply radiates from system pipes and hardware can be retarded by the proper use of insulation, which pays for itself many times over in reduced fuel expenditures.

End-use applications of steam involve the transfer of latent heat content to process materials. A variety of heat exchangers accomplish this task. Monitoring and maintenance ensure reliable, safe operation of heat transfer. The maintenance effort not only ensures energy efficiency; it contributes to system reliability, overall plant productivity, and workplace safety.

Recovery stages of steam operations involve recirculation of excess heat and water as well as treatment of combustion gases. Steam that is discharged as excess from one part of the process can be redistributed as input to another stage. Cooled steam, or condensate, also offers residual thermal value that can be reused instead of being uselessly discharged to the environment. The recovery of thermal resources—including combustion heat, direct-process application, and residual steam—all serve as a means for reducing expenditures on fuel and other steam inputs.

Business Forces

Business forces acting upon the firm originate from various sources—some internal, some external to the firm. Some reflect the competitive market place, while others represent internal operating and corporate priorities. Other forces are derived from supplier or regulatory issues.

OPERATING PLANT PRIORITIES. Every piece of machinery in a manufacturing facility is an asset that is expected to generate income for the firm. To satisfy this objective, steam facility managers ensure system reliability and (when possible) optimize operating load factors. Reliability, as the goal of maintenance and repair procedures, is a precondition for realizing an economic return from production assets. Reliability and optimal load factors contribute to consistent (i.e., less volatile) operating income. "Operating income" refers to the value realized by a production process after subtracting cost of goods sold plus expenses from operations, maintenance, depreciation, amortization, and administration from the revenue generated from the sale of final goods. Operating income, when expressed as a percentage of revenue, is the *operating margin*. This is one financial variable that the corporate office depends on when comparing the worth of production facilities. Operating margins can be improved through increased steam efficiency—and corporate financial officers will respond positively to initiatives that improve operating margins. Table 1 illustrates a hypothetical company's operating margin, improved through applied steam efficiency measures. This case will be further developed in subsequent examples.

CORPORATE OFFICE PRIORITIES. The corporate office must respond to stakeholders both inside and outside the firm. These interests form corporate priorities. The on-going success of the firm in part depends on how well its corporate officers can raise external capital, turn that capital into working assets, competitively deliver products to the marketplace, and distribute earnings. Asset management is a central

TABLE 1: IMPACT ON OPERATING MARGIN

ABC Manufacturing Co.
ANNUAL INCOME STATEMENT

Dollars in Thousands	Before Steam Efficiency Implementation	After Steam Efficiency Implementatio	Impacts Posititve (+) Or Negative (-)
Revenues (or Sales):	**$10,000**	**$10,000**	**$0**
Cost of goods sold:	4,000	4,000	0
Operations & maintenance:	2,000	1,870	+130
Labor……………………..	1,200	1,300	-100
Materials………………..	100	120	-20
Fuels……………………..	700	450	+250
Depreciation:	200	205	-5
Amortization:	200	205	-5
General & administration:	100	105	-5
Total operating expenses:	6,500	6,385	+115
Operating income:	**$3,500**	**$3,615**	**+115**
Interest expense:	500	500	0
Income before taxes:	3,000	3,115	+115
Income tax (50%):	1,500	1,558	-58
Net income:	$1,500	$1,557	+57
Operating margin = Operating income/revenue	**35.0%**	**36.2%**	**+1.2%**

Discussion: *ABC Co. upgrades its boiler facilities with efficient burner hardware and also implements a rigorous steam system diagnosis and maintenance program. Routine monitoring is stepped up while faulty steam traps and valves are replaced. The effort increases labor, materials, and G&A expenses, but the increase is more than offset by savings in fuel purchases.* ***Operating margin****, which measures the financial returns attributable to the manufacturing operations only (thus excluding taxes and interest), improves from 35.0% to 36.2%*

NOTE: Fictional company and financials depicted for illustration purposes only.

concern in accomplishing these goals. The earnings not distributed to shareholders can be used to upgrade the firm's asset base. The capital budget process allows corporate officers to review and select the opportunities for investing in assets.

Any capital budget proposal for an investment in steam efficiency should compare the cash outlay with the returns that outlay will generate. A strong proposal is one that excels in two ways. First, the volume of savings generated should be comparable to or better than other capital budget opportunities. Second, it should demonstrate a rapid *payback*—i.e., the length of time over which expense savings accumulate to surpass the initial outlay. Successful proposals generate additional returns, making more working capital available to the firm. Proposals should also be described in terms of the time required to achieve those savings. An alternative financial metric is *return on investment* (ROI). This relates annualized savings to an initial outlay. The result is a percentage or *rate of return* that can be compared to the rate on other capital budget alternatives or the interest rate at which capital is borrowed from outside lenders. In cases where company-wide efficiency programs are implemented, it may be particularly effective to describe savings in terms of additional *earnings per share* (or *EPS*) paid to shareholders (Energy Cost Savings Council, 1999; Wingender and Woodroof, 1999). Table 2 illustrates the imaginary ABC Company's payback, ROI, and EPS attributable to an investment in high-efficiency burner retrofit to an existing boiler and related insulation material. This example continues the data displayed in Table 1.

The impact of steam efficiency on shareholder wealth can easily be demonstrated with one additional piece of data. The publicly-held firm will demonstrate a current market value for its stock—the price-to-earnings or "P/E" ratio. This ratio relates the current stock market value of the company's stock to the corporation's most recent annual earnings.

Shareholder wealth is a multiple of earnings (i.e., earnings multiplied by the P/E ratio). Similarly, an increment to earnings can be multiplied by the P/E ratio to determine a corresponding impact on shareholder wealth. Table 3 illustrates this impact for ABC. Co. The corporation's board of directors also has the option of entering or exiting product markets. If a diversified corporation wants to enter a product market, one sure way is to acquire an incumbent firm in that market. Accordingly, the addition or sale of entire manufacturing facilities follows on the heels of such decisions. Even the *possibility* of participation in merger or acquisition activity will influence asset management decisions. A facility with top-notch maintenance should, with all else being equal, command a premium acquisition price. In this sense, quality maintenance of steam systems contributes to the financial attractiveness of a target manufacturing facility. Investment in steam efficiency, which has positive impacts on operating margins, would therefore enhance the market value of a target facility.

COMPETITIVE MARKET DYNAMICS. Competition has implications for manufacturing conduct both inside the industry (rivalry among competitors) and in the positioning of products in the marketplace itself. This discussion of competitive dynamics covers the "market-side" implications of competition. A discussion of "intra-industry rivalry" follows this.

One major business force imposed by the marketplace is the increasing consumer demand for

TABLE 2: PAYBACK, ROI, AND EPS

ABC Manufacturing Co.					
Dollars in Thousands	*Year 0*	*Year 1*	*Year 2*	*Year 3*	*Year 4*
Impacts on Net Income					
A. Net income w/out implementation (a)	-	*$1,500*	*$1,500*	*$1,500*	*$1,500*
B. Net income with implementation	-	*1,557*	*1,557*	*1,557*	*1,557*
C. Improvement in net income (annual):	-	*$57*	*$57*	*$57*	*$57*
D. Initial investment in burner, etc.:	*$125*	-	-	-	-
Impacts on Working Capital:					
E. Cumulative investment recapture:	*$0*	*$57*	*$114*	*$125*	*$125*
F. Cumulative impact on working capital:	*-125*	*-68*	*-11*	*+46*	*+103*
Earnings per Share (EPS):					
G. EPS without implementation:	-	*$1.50*	*$1.50*	*$1.50*	*$1.50*
H. EPS with implementation:	-	*1.56*	*1.56*	*1.56*	*1.56*
I. Improvement in EPS:	-	*+0.06*	*+0.06*	*+0.06*	*+0.06*

Payback = D) C, *or*
$125) $57 = 2.2 years

simple ROI = C) D, *or*
$57) $125 = 45.6%

EPS = net income) average number of shares outstanding*, or*
$1,557,000) 1,000,000 = $1.56 after implementation

Discussion: *ABC Company implements its steam efficiency program with an investment of $125,000 from working capital, so there are no borrowing costs. The implementation improves net income by $57,000 annually. These savings accrue so that the investment has a* ***payback*** *(that is, "pays for itself") after 2.2 years of operating with the implementation in place. The* ***simple return on investment (ROI)*** *expresses annual savings as a percent of the original outlay. The improved earnings (or net income) can be expressed as additional* ***earnings per share****, or incremental earnings per share of common stock of ABC Company.*

NOTE: Fictional company and financials depicted for illustration purposes only.
(a) "Net Income" is the same as "earnings," See Table 1 for full development of net income.

TABLE 3: STEAM EFFICIENCY IMPACTS ON SHAREHOLDER WEALTH

ABC Manufacturing Co.
Dollars in Thousands

A. Current annual earnings w/out implementation: (a)
B. Annual earnings with implementation:
C. Improvement in annual earnings: $1,500
$1,557
$57

Current stock price: *$39 per share*
Most recent annual earnings per share (from Table 2): $1.56
Current P/E ratio: $39) $1.56 = 25

Impact of steam efficiency implementation on shareholder wealth:
25 x $57,000 = $1,425,000

Discussion: *The steam efficiency implementation (outlined in Table 2 above) yields a net impact of $57,000 in additional earnings per year. The additional earnings can be equated to new shareholder value. Since ABC Co.'s stock currently sells at 25 times earnings, this price-earnings ratio is multiplied against the new earnings to produce a $1.4 million gain in shareholder value.*

NOTE: Fictional company and financials depicted for illustration purposes only.
(a) The terms "net income" and "earnings" are used interchangeably.

variety and customization of products. What is at stake for the corporate office is *market share*, which is the proportion of total industry output provided by one firm in that industry. Firms that serve consumer markets struggle to accommodate rapid changes in taste in order to stay competitive. In the factory, shorter production runs and more frequent changes in production set-up are imposed, especially in the latter stages of a process. This, more than any other business force, may work against the pursuit of steam efficiency. The race to achieve flexibility implies more of an investment in direct process equipment, especially robotics and automated controls. Such capital-intensive investment may leave little in the budget for steam efficiency. Still, to the extent that early stages of a production process are relatively free from hardware changes, then steam efficiency is still a viable way to save money. In general, whenever higher volumes of energy are used at consistently high load factors (especially with bulk or commodity processes), then the economics of steam efficiency yield a faster payback.

Steam efficiency may impact market dynamics in another way. Environmentally conscious consumers are growing in number, and this population is increasingly adept at using their buying power to reflect their sentiments. Specifically, "green-image" branding is marketing tool that caters to this audience. Manufacturers that adopt resource-sensitive production policies incorporate this fact into their marketing—promoting a "green image" that resonates with certain consumers. In many instances, "green" products command a price premium in the marketplace. Steam efficiency, as a business practice, facilitates this branding strategy. As a part of an overall green-image branding strategy, steam efficiency would not only reduce operating expenditures, it may permit premium product pricing. Both are positive outcomes from the corporate perspective.

Another benefit from increased market share is the *economies of scale* that are captured when production is expanded. Economies of scale refer to volume discounts in purchasing inputs as well as increased output per hour or per volume fixed assets. Table 4 illustrates market share and

TABLE 4: IMPACT OF "GREEN IMAGE" ON MARKET SHARE AND INCOME

ABC Manufacturing Co. ANNUAL INCOME STATEMENT Dollars in Thousands	With 33% Market Share	With 43% Market Share	*Changes Positive (+) or Negative (-)*
Revenues (or Sales):	*$10,000*	*$12,900*	*+$2,900*
Cost of goods sold:	*4,000*	*5,100*	*-1,100*
Operations & maintenance:	*1,870*	*2,300*	*-430*
Labor……………………………..	*1,300*	*1,640*	*-340*
Materials………………………..	*120*	*125*	*-5*
Fuels……………………………..	*450*	*535*	*-85*
Depreciation:	*205*	*205*	*0*
Amortization:	*205*	*205*	*0*
General & administration:	*105*	*150*	*-45*
Total operating expenses:	*6,385*	*7,960*	*-1,575*
Operating income:	*$3,615*	*$4,940*	*+$1,325*
Interest expense:	*500*	*500*	*0*
Income before taxes:	*3,115*	*4,440*	*+1,325*
Income tax (50%):	*1,558*	*2,220*	*-662*
Net income:	*$1,557*	*$2,220*	*+$663*

***Discussion**: The $30 million market for paper cups is served by three incumbent firms. ABC company competes with PQR Co. and XYZ Co. All three firms produce a very similar paper cup product, and nothing else. All aspects of production are similar across all firms. This includes acquisition of inputs, manufacture, packaging, distribution, and sales. Each firm serves a similar cross-section of restaurant supply vendors and consumer retail outlets. Accordingly, each firm captures about one-third of the national market, or about $10 million each.*

ABC Company responds to increased public concern with manufacturing plant impacts on surrounding areas and on air and water quality in general. More importantly, it is noted that consumers will use their purchasing power to reward firms that operate clean-operating manufacturing facilities that minimize their impact on the environment.

*ABC Co.'s strategy is to adopt a public image of environmental responsibility in its manufacturing processes. This positioning is implemented in its media campaigns. It is substantiated in part by ABC's implementation of a steam efficiency program (see discussions in Tables 1&2). This media campaign allows ABC Company to capture another 10% of the market—its **market share** grows from 33% to 43%. ABC Co. has sufficient idle capacity to step up production without adding new production facilities.*

Paper cup market = $30 million

*ABC Co. **market share** before environmental media campaign = 33%, or $10 million*

*ABC Co. **market share** after media campaign = 43%, or $12.9 million*

*Competitors' **market shares** after media campaign = 57% combined, or 28.5% each*

*Notice that as ABC Company enjoys larger sales, some **economies of scale** are captured in manufacturing. Therefore, as sales increase from $10 million to $12.9 million (an increase of 12.9%), not all expenses increase by the same proportion. Specifically, ABC Company now enjoys greater volume discounts for materials purchasing and inputs like fuel and related operating materials. The "environmentally friendly" media campaign adds to advertising costs (under "general & administrative"). But overall, net income—the bottom line—improves.*

NOTE: Fictional company and financials depicted for illustration purposes only.

TABLE 5: IMPACTS ON SALES MARGIN AND RETURN ON ASSETS

ABC Manufacturing Co. SELECTED FINANCIALS Dollars in Thousands	*Before* Steam *Efficiency Implementation*	*After* Steam *Efficiency Implementation*	*After Media* Campaign & *Change in Market Share*	Cumulative Changes *Positive (+) or Negative (-)*
Total assets:	*$5,000*	*$5,010*	*$5,010*	*+$10*
Revenue:	*$10,000*	*$10,000*	*$12,900*	*+$2,900*
Net income after tax (NIAT):	*$1,500*	*$1,557*	*$2,220*	*+$720*
Margin on sales = NIAT/revenue	***15.0%***	***15.6%***	***17.2%***	***+2.2%***
Return on assets = NIAT/total assets	***30.0%***	***31.1%***	***44.3%***	***+14.3%***

Discussion: *ABC Company improves its sales margin from 15.0% to 17.2.%. ABC Company has publicly traded stock, so its financials are freely available. A conglomerate firm notices ABC Company. The coglomerate seeks to improve its overall financial performance by exiting a product market in which it earns a 16% margin on sales. It would sell its production facilities for that market and purchase ABC Company to add this better performer (17.2%) to its portfolio.*

Meanwhile, a pension fund analyst likes the prospects of the paper cup market and decides to invest in one of the industry's better manufacturers. The analyst compares the financial performance of ABC Company with its competitors, PQR and XYZ Companies. One of the deciding factors for the analyst in selecting the best company is **return on assets**, or how efficiently the assets are used from a financial perspective. The 44.3% ROA achieved by ABC Company, thanks to its steam efficiency program and media campaign, make it stand out from the competitors.

NOTE: Fictional company and financials depicted for illustration purposes only.

economy-of-scale impacts, continuing with the fictional example of ABC Company.

INDUSTRY PERFORMANCE BENCHMARKS. The business challenge for manufacturers is to compete on the basis of price, or through superior delivery or customer service. In many instances, where there is little differentiation among products produced by competing firms, then production costs become a basis for competition. A financial metric used by the corporate office in this competitive environment is *margin on sales*, which relates annual net income to annual revenue. Corporations that have diverse product lines will rely on this statistic to evaluate the potential entry into or exit from a particular product market.

A component of competition is manifested in the equity (stock) performance of publicly-held corporations. Wall Street security analysts provide the investor community with opinions about corporations' future earning capacity. To a large extent, such opinions are based on metrics that compare the operational and financial performance of one company to another. And since top managers in manufacturing are held accountable for stock performance, their management priorities are largely driven by stock analysts' metrics. Revenue, expenses, and income are expressed on a per-unit basis to compare operational efficiency among different plants and corporations. Another statistic, *return on assets* (ROA), allows financial analysts to compare how well plant facilities are utilized. The total assets held by a firm are used to generate an income stream. For two plants that have similar assets, differences in management will be reflected in different rates of return. Stated differently, one facility manager may make the same assets "work harder" than another manager would. ROA is also used by security analysts to compare corporate performances. Table 5 demonstrates the possible

TABLE 6: IMPACT ON COST PER UNIT PRODUCED

ABC Manufacturing Co. *ANNUAL INCOME STATEMENT* *Dollars in Thousands*	*Before Steam Efficiency Implementation*	*After Steam Efficiency Implementation*	*After Media Campaign & Change in Market Share*	Cumulative *Changes Positive (+) or Negative (-)*
Revenues (or Sales):	*$10,000*	*$10,000*	*$12,900*	*+$2,900*
Total oper. expenses:	*6,500*	*6,385*	*7,960*	*-1,460*
Operating income:	*$3,500*	*$3,615*	*$4,940*	*+$1,440*
Interest expense:	*500*	*500*	*500*	*0*
Income before taxes:	*3,000*	*3,115*	*4,440*	*+1,440*
Income tax (50%):	*1,500*	*1,558*	*2,220*	*-720*
Net income:	*$1,500*	*$1,557*	*$2,220*	*+$720*
Units produced (a):	*1,000,000,000*	*1,000,000,000*	*1,290,000,000*	*+290,000,000*
Units per case:	*1,000*	*1,000*	*1,000*	*0*
Cases produced:	*1,000,000*	*1,000,000*	*1,290,000*	*+290,000*
Revenue per case:	*$10*	*$10*	*$10*	*0*
Oper. cost per case:	***$6.500***	***$6.386***	***$6.170***	***+$0.330***
Oper. income per case:	***$3.500***	***$3.614***	***$3.830***	***+$0.330***

Discussion: The paper cup market represents 3 billion units annually. ABC Company experiences cost reductions attributable to its steam efficiency program (see Table 1), and its *market share* is boosted by media positioning as an "environmentally friendly" manufacturer (Table 3). ABC Company's competitive performance improves accordingly with each action. The steam efficiency program reduces operating expenses, which allows the company to achieve a savings in operating **cost per unit** (or **per case** in this instance) of $0.114. Additionally, the media campaign increases ABC Company's market share, which in turn lets the company attain **economies of scale** in production. That increases operating cost savings per case by another $0.216. The cumulative improvement in cost (and subsequent increase in operating income) per case is $0.330.

ABC Company reviews this improvement in cost per unit and now considers acquiring one of the other two competitor companies, thus growing its market share from 43% to 71.5%.(b) ABC Company could apply its steam efficiency methods to the newly acquired facility. This may improve the profitability of the new plant, if debt from the acquisition is adequately covered by the new increment of net income.

NOTE: Fictional company and financials depicted for illustration purposes only.

(a) This line and lines below NOT in thousands.

(b) Anti-trust considerations are ignored for now. The anticipated market share is 43% + 28.5% = 71.5% (see Table 3).

impact of these metrics for the fictional ABC Company.

A key financial metric situation serving a similar purpose is *cost per unit* produced (or per unit of volume or weight). A common use for cost per unit is as a benchmark for devising volume discounts to distributors. It is also a way to compare the cost efficiency of different plants that produce the same product. Table 6 illustrates the fictitious ABC Company's experience with managing cost per unit.

EMISSIONS CONTROLS. Industrial facilities that produce atmospheric emissions over certain threshold limits face possible pollution control liabilities under the federal Clean Air Act. Larger steam facilities, typically in refining, chemical processing, and pulp and paper manufacturing, are usually of a scale that makes this regulation applicable to their operations. Regulation put limits on the volume of pollutants that can be released by a facility over a period of time. These pollutants include sulfur dioxide (or SO_2, which generates acid rain) and nitrous oxides (NO_2 and NO_3, commonly referred to as NO_x, which are ozone depletion agents). The limits set on pollution emissions are backed by penalties. In worst cases, the penalties involve fines and imposed shutdowns.

Steam efficiency is a remedy for emission liabilities in several ways. First, reduced fuel consumption means less emissions output. Second, the steam operator's efforts to maintain system reliability will necessarily include burner efficiency measures. Cleaner combustion is an added benefit of optimal burner operation. In addition, on-going system monitoring and maintenance will ensure that combustion and emission problems are detected and resolved before they cause problems. Corporate decision-makers should understand that diligent maintenance of steam systems will not only reduce fuel consumption, it will preclude unforeseen expenses such as emissions penalties—or worse, loss of revenue that comes with shutdowns due to non-compliance with regulation.

Depending on the scale and location of an industrial facility, the operations manager may have the option of generating non-process revenue from salable emissions credits. The Clean Air Act enabled the U.S. Environmental Protection Agency to develop a program for reducing the overall tonnage of SO_2 and NO_x pollutants emitted by power generating facilities (U.S. EPA, 1999). It does so by providing a market for trading surplus emissions "credits" among designated source facilities. Statutory annual thresholds indicate the emissions level that a source facility should attain. When facilities restrict more than their share of emissions, the surplus reduction becomes a credit that can be sold to other facilities that cannot meet their emission thresholds. While this program targets electric power generators, eligible manufacturing facilities may voluntarily opt-in to emissions credit trading to generate credits that are sold to power generators. Steam efficiency programs can assist in generating these credits by reducing fuel inputs, thus lowering combustion emissions below target thresholds. By selling the credits, the manufacturing facility generates non-process revenues.

SAFETY/OSHA CONCERNS. The benefits of well-disciplined steam system monitoring extend beyond reduced fuel expenditures, pollution liability containment, and system reliability. It also encompasses workplace safety. System monitoring efforts will detect potential hazards before they cause damage to life and property. A corporate audience will appreciate protection from unforeseen or *extraordinary expenses.* The investment in steam system efficiency monitoring will save the firm from penalties related to non-compliance with Office of Safety and Health (OSHA) regulations. It will also reduce the risk of catastrophic events that result in lawsuits against the firm for injuries stemming from lapses in workplace safety. A steam efficiency program that demonstrates attention to safety should be reflected in a reduction in accident and injury levels. That program should also justify a reduction in insurance premiums.

ENERGY PURCHASING AND UTILITY CONCERNS. For years, steam facility operators had few real choices in fuel inputs. Coal has long been a favorite fuel source for industrial operators due its low acquisition price. Although coal poses additional handling costs and emission liabilities, it remains a cost effective fuel choice for large-scale, high load-factor steam operations. The increased availability of natural gas makes it a viable alternative to coal in some circumstances. Natural gas, which features a very clean combustion profile, is also an attractive alternative for facilities that are concerned with emission liabilities. Fuel oil is a situational favorite, especially when steam systems are used for back-up power generation.

Deregulation of energy markets changes the nature of fuel purchasing. Increasingly, energy markets are opening up so that new providers can supplement sole-source energy utilities. While the new competition will generally bring down energy prices, it presents a new layer of concerns for the steam facility operator. Specifically, there are questions about reliability of supply when fuel is purchased through independent marketers. The industry is still new and subject to shake-up as energy marketers start up, merge, fail, and otherwise change the profile of their industry on a daily basis. Many industrial facility managers put a high value on reliability, and are willing to pay a premium for secure fuel supply.

Changes in the energy industry have led to the creation of energy service companies (ESCOs), which offer energy management services in addition to commodity fuel provision. Manufacturers now have the option of contracting part or even all of their steam operation to ESCOs. To bid for this business, the successful ESCO must provide superior value through a combination of cost savings or enhanced reliability. The ESCO will certainly include steam efficiency measures as a way to keep its cost to the industrial customer as low as possible. By outsourcing its steam operations, the corporate office may witness overall savings through reduced capital expenditure (since the ESCO retains title to the steam equipment) and perhaps through reduced operating expenditure. Even though steam provided through an ESCO is a new expense item, its cost may be more than countered by the ESCO's ability to produce steam cost effectively. Competitive ESCOs enjoy large-volume fuel purchasing discounts and retain engineering expertise to assist in steam system maintenance.

Conclusion

Industrial steam efficiency has benefits far beyond simply responding to an audience of regulators. The costs of generating steam are significant and indeed controllable. The impacts of steam efficiency are directly reflected in fuel expense savings. Many additional indirect benefits are possible, including the avoidance of emission control penalties and reductions in hazard insurance premiums. Steam maintenance programs that routinely monitor and correct irregularities will yield better reliability, safety, and asset longevity.

Consumers increasingly purchase "environmentally-friendly" products when the option is available, so firms that publicize their embrasure of energy-conserving technologies may benefit by doing so.

Corporate decision-makers respond to a variety of business forces coming from within and beyond the firm. The firm's financial strategies, in particular, will be driven by the dynamics of those forces. Corporate decision-makers will naturally give greater consideration to investment alternatives that respond effectively to prevailing business forces. The steam facility manager competes for capital funds with, for example, managers of direct production, information systems, warehousing, and transportation. The steam manager will be better equipped in this internal competition for funds by presenting investment proposals that clearly illustrate the impact of steam efficiency on overall financial performance.

Steam facility managers that seek informational resources to help them in this task are encouraged to contact the BestPractices Steam program, sponsored by the U.S. Department of Energy and the Alliance to Save Energy.

For More Information

The BestPractices Steam program is co-managed by the U.S. Department of Energy and the Alliance to Save Energy, a Washington, D.C.-based non-profit that supports national energy management initiatives. Industrial end users, equipment suppliers, and resource organizations act together to help industry stay competitive and promote the comprehensive upgrade of industrial steam systems. Contact the DOE Office of Industrial Technology Clearinghouse at:

E-mail: steamline@energy.wsu.edu

Phone: (800) 862-2086

See also the BestPractices Steam website:

www.oit.doe.gov/steam

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Department of Energy Best-Practices: Keeping Industry Competitive Through Steam System Management

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SUMMARY

The Department of Energy's Office of Industrial Technologies collaborates with industry to improve steam systems. This improves plant reliability, environmental performance, and lowers operating costs. Typical plants can improve steam efficiency by 20-30%. Opportunities exist in steam generation, distribution, end use and recovery. Available resources include tip sheets and handbooks. Rohm Haas, Georgia-Pacific, and Bethlehem Steel are just a few plants that have documented cost, emission and energy savings from steam system improvement.

ABSTRACT

The Department of Energy Office of Industrial Technologies' BestPractices works collaboratively with industry to capture long-term energy efficiency opportunities through its Industries of the Future program. Near-term opportunities are captured through BestPractices. In the area of steam, BestPractices provides industry with easy access to solutions to enhance energy efficiency and environmental performance, increase reliability and safety, and lower operating costs for their total manufacturing plant. Over 50% of fuel used by industrial manufacturing plants is used to generate steam. A typical plant can improve the efficiency of their steam system by 20-30% Improvement opportunities exist in steam generation, distribution, end use, and recovery. Resources for better steam system operation and maintenance include handbooks, BestPractice tip sheets, training course lists and software. These are available through the Industries of the Future Clearinghouse (800) 862-2086, via email (steamline@energy.wsu.edu) and the web site (www.oit.doe.gov/steam). Emissions, cost, and energy savings from steam system improvement have been seen at an array of manufacturing sites, including Rohm and Haas chemical plants, Georgia-Pacific plywood mills, and a Bethlehem Steel plant.

KEYWORDS

Steam, energy management, manufacturing, industry, technical assistance, systems

BESTPRACTICES BASICS

The DOE Office of Industrial Technology's (OIT) BestPractices aims to assist industry in adopting near-term energy-efficient technologies and practices through voluntary, technical assistance programs. BestPractices encompasses motors, compressed air, steam, and process heating systems. In conjunction with the Alliance to Save Energy, a nonprofit coalition of prominent business, government, environmental, and consumer leaders who promote the efficient and clean use of energy worldwide, and industry steam experts, a network of resources has been established. Steam-using industrial plants use these resources to adopt a systems approach to designing, installing and operating boilers, distribution systems, and steam applications. The focus of commercially available steam efficiency information has been on particular components or technologies rather than whole systems. The need for a total-system focus from an unbiased source drives BestPractices' collection of steam efficiency resources. Benefits of the systems approach include improved financial performance, lower emissions, increased plant operation reliability, and increased productivity.

WHY CARE ABOUT STEAM ?

Steam is essential to plant productivity. Steam system performance can affect the operation of an entire plant. Common applications include: process heating, process drying, mechanical drive, space heating, and power generation. Alliance research indicates that over 50% of the input fuel used by the U.S. manufacturing sector is used to generate steam. This is an estimated annual cost of $18 billion for the approximately 33,000 boilers used by industry [1]. The annual energy cost of a boiler is often several times its purchase price. Steam costs generally range from under $4 to $6 per 1,000 lbs. of steam, depending largely on fuel costs. More importantly, industrial plants can cut costs, with a typical 20-30% improvement in steam system efficiency, i.e. meet their steam needs with 20-30% less fuel. Steam intensive sectors which stand to benefit the most by improving their steam systems include pulp and paper, chemicals, food processors, steel mills, petroleum refining, and textiles.

The priorities to maintain high productivity, achieve high utilization rates and high reliability (downtime being dearly expensive), and reduce operating costs are all supported by improving steam system performance. Steam system enhancement keeps manufacturers competitive because it:

- Increases equipment life, yielding lower repair/replacement expenses, downtime and maintenance costs.
- Increases plant productivity through higher heat transfer rates (rapid batch heat-up) and increased throughput.
- Promotes pollution prevention through lower emissions and lower treatment chemical and wastewater costs.
- Improves quality control through the resulting temperature control accuracy.
- Decreases equipment failure risk of catastrophic accidents, potentially lowering hazard insurance premiums.

Unfortunately, several barriers to greater system efficiency exist in today's marketplace. These include a lack of awareness of the efficiency improvement opportunities. Time and resources are not then given to providing sufficient training, maintenance, and proper operation. An even greater hurdle in energy management is getting support from financial decision-makers within the company. The benefits of energy efficiency are not generally translated into the figures this group appreciates and uses to evaluate investment options. On the accounting side, fuel costs barely show up on many company income statements because of the accounting focus on direct process inputs, the tendency to report all utilities as a single line item, and low energy prices. Steam is often separated from other factors of production, both physically and in the accounting system. As a result steam costs are not assigned to individual processes or production lines, but rather treated as an uncontrollable cost of doing business.

Steam should be treated as a manageable asset worth company investment. Compelling communication of successful energy management to corporate executives is particularly important. By accounting for the total financial benefits of projects, a strong case can be made for system upgrades, based on the experience of the Department of Energy. Available tools for constructing this case include a Toolbook for Energy Efficiency and case studies (see Resources section).

Systems Approach

Optimizing steam system performance requires a systems approach, as downstream system changes can have impacts at the boiler, and vice versa. Systems must be able to handle steam demand variation over time. Further, focusing on individual components will often overlook the real cost-saving opportunities. Steam system categories include generation, distribution, end use, and recovery. In assessing system needs, the end-use steam requirements should be evaluated first. Afterwards, system designers should work upstream in assessing system changes, up to the generation stage.

Performance Improvement Opportunities

Keeping the system approach in mind, there are nevertheless common areas in steam systems that offer savings opportunities:

Generation

- **Boiler Maintenance.** Efficiency levels can be improved by 2 to 5 percent with boiler tune-ups and auxiliary equipment where economically justified [2]. Clean water and fire-side surfaces should be maintained; scale can reduce heat transfer and cause a loss of boiler efficiency of as much as 10 to 12 percent [3].
- **Blowdown.** Optimization (assuming appropriate levels of condensate return) reduces the total dissolved solids in feedwater to help keep the water-side surface clean and minimizes the amount of cool feedwater increasing heat demand. Installing a continuous blowdown heat recovery device raises boiler energy efficiency
- **Water Treatment**. Reduction of water impurities reduces scale on heat transfer tubes and surfaces and reduces corrosion of system components.

- **Boiler Controls**. Multiple burner control coupled with air trim control can result in fuel savings of 3 to 5 percent [4].
- **Stack Gas Losses.** Substantial energy losses in the boiler are caused by waste heat literally going "up the chimney." Reducing these stack losses is probably one of the greatest opportunities to improve steam generation efficiency. The three basic strategies for minimizing stack gas heat loss are:

  (1) Optimize fuel-to-air ratio in combustion

  (2) Keeping heat transfer surfaces clean

  (3) Adding flue gas heat recovery equipment where justified

  Combustion controls and waste heat recovery equipment can increase boiler efficiency about 1.0 percent for each 15 percent reduction in excess air, 1.3 percent reduction in oxygen, or 40°F reduction of stack gas temperature.

Distribution

Steam distribution savings can be substantial, especially in systems which have not been maintained.

- **Piping Design**. Steam piping should be properly laid out for adequate drainage and air venting. Distribution piping should also be designed for appropriate pressure drops from generation pressure to the end-use pressure requirement.
- **Steam Leaks**. Leaks in neglected areas might be found in the piping, valves, process equipment, steam traps, flanges, or other connections.
- **Steam Traps.** Proper selection, sizing, and maintenance of distribution system steam traps is important. Techniques for identifying failed traps include visual, acoustic, electronic, and temperature. Energy efficiency gains of 10 to 15 percent are common when steam traps are actively maintained, as 15-20% of steam traps in a typical system have failed. Vigilant maintenance can reduce this number to 5%. Armstrong International estimates that, on average, each defective trap wastes over 400,000 lbs. of steam a year, worth over $2,000 [5].
- **Insulation.** Insulation of distribution system pipes, flanges, and valves improves system operation. Plants audited under DOE's Industrial Assessment Center program demonstrated a savings potential ranging from 3 percent to as high as 13 percent of total natural gas usage on average through insulation installation.

Recovery

Inadequate maintenance can result in inadequate operation of steam traps, substandard treatment of distribution system water, and allow hot condensate to be wasted.

- **Heat Recovery.** Economizers and preheaters take waste heat and return it for use to the boiler feedwater and the combustion air, respectively.
- **Condensate Return.** Condensate provides warm, pure water that when returned reduces make-up water for the boiler and the amount of water treatment chemicals needed. Energy used to heat cold makeup water is a major part of the heat delivered for use by the steam system, requiring an additional 15 to 18 percent of boiler energy for each pound of cold makeup water. Condensate return also reduces water discharge needs.
- **Flash Steam Separators.** Separators provide opportunities to create low pressure steam for possible reuse and removal of noncondensable gases.

Resources

Participation in co-organized private industry workshops is one of the best ways to comprehensively receive private and public steam and energy system solutions. These workshops provide peer networking opportunities to share experiences in energy management. Information on these and other steam efficiency opportunities is available on the Steam BestPractices web site (**www.oit.doe.gov/steam**), which provides:

- Technical assistance
- Case studies
- Workshop notices
- Project financing tools such as the Toolbook, ESCO lists, and cost-sharing opportunities
- Lists of technical tools, references, standards and training opportunities

The Industries of the Future Clearinghouse has also been established to provide information and technical assistance. To contact the Clearinghouse:

E-mail: **steamline@energy.wsu.edu**
Phone: **(800) 862-2086**

Publications

A comprehensive list of commercial training opportunities for better operation of steam distribution systems and boilers is available online. Also on-line are Technical References and Standards for maintaining and operating steam systems, categorized into steam generation, distribution, end use, and recovery. Documents available at the web site and/or the Clearinghouse include:

- BestPractices Steam Tip Sheets
- Council of Industrial Boiler Owners Energy Efficiency Handbook for Powerhouse Operators
- 3-E Plus Insulation Software to determine optimal insulation thickness
- Oak Ridge National Laboratory Insulation Guidelines
- Business Impacts of Steam Efficiency paper
- May 1998 Fortune article, "*Turn Down the Energy, Tune Up the Profits*"
- May 1999 Energy Matters supplement on steam system management
- Steam System Optimization and Boiler Steam Quality papers
- 1998 Industrial Energy Technology Conference Steam Session Papers

RESULTS

Manufacturers are encouraged to submit steam system projects and data for case study development. The company receives recognition for their efforts and receives publicity as an example of what similar companies might achieve. Case studies are only published with the full support and agreement of the participating company. Successful projects include:

At a Rohm and Haas plant in Kentucky, the production process for methyl methacrylate products uses 540,000 lbs./hr of steam on average. A survey of the plant's 1,500 steam traps indicated that 12%, or 180 traps, were failing and wasting steam. Plant management decided to replace all the traps over the next year and regularly sought out failed traps, thereafter, as part of a formal steam trap inspection and maintenance program. By doing so, the company saved nearly $500,000 each year. By implementing a complete program of personnel training, inspection, and trap maintenance and replacement, the company realized a payback of 22 days per trap [6].

Bethlehem Steel increased the capacity and efficiency of a steam turbine generator system by: (1) rebuilding the turbine to incorporate the latest steam path technology; (2) using a portion of the warm condenser cooling water exhaust stream instead of cool lake water for boiler feedwater makeup; and (3) injecting the low-pressure steam previously used to heat the lake water into the turbine. The project reduced high-temperature water discharge into the harbor and decreased coke-oven and blast-furnace gas emissions. Annual reductions included: 27,200,000 lbs. of carbon equivalent, 294,000 lbs. of SOx, 370,000 lbs. of NOx, 11,600 lbs. of PM_{10}, 1,450 lbs. of VOCs, and 14,000 lbs. of CO. Other annual savings were approximately 40,000 MWh of electricity, 85,000 MMBtu of natural gas, and nearly $3.3 million. With a cost of $3.4 million more than a standard maintenance overhaul, the project had a simple payback of just over one year [7].

Georgia Pacific's plywood plant in Madison, Georgia, insulated several steam lines leading to its dryers. Because the steam lines were uninsulated, heat was being lost, resulting in lower temperatures in the steam lines, making the drying process less efficient. Consequently, Georgia Pacific sometimes had to buy fuel to make up for thinning supplies of bark. The installation of insulation made the work environment safer and improved process efficiency. The plant reduced its fuel costs by roughly one-third over the year with the drastically lowered heat loss. The project also lowered emissions: 9.5 million lbs. of carbon dioxide (carbon equivalent), 3,500 lbs. of SOx, and 26,000 lbs. of NOx on an annual basis [8].

CONCLUSION

As a first step, any reader of this article in manufacturing should walk through their plant to look for some of the opportunities for savings and decide what additional resources are needed for better operation. Second, look at the web site and call the Clearinghouse to find what is available in terms of training and technical assistance. And third, if there is not enough support from upper company management, approach them with some information on what is needed to be done in the plant together with information on financing opportunities available from the BestPractices program to sell the project.

Too many manufacturing facilities are not achieving their full potential because of poorly-operating steam systems. Steam efficiency lies at a rarely visited intersection of improved economic performance, greater energy-efficiency, and environmental benefit; a win-win-win situation. Through the adoption of BestPractices, the Alliance to Save Energy, the Department of Energy's Office of Industrial Technologies (DOE-OIT), and industry leaders have a solution for steam system problems that benefits the public, industry, and environment. Further, the Department of Energy BestPractices is a gateway beyond steam to a comprehensive array of research, advanced technology, technical assistance, and financing programs offered by DOE-OIT to improve company energy, environmental, and economic performance.

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4. Ibid.

5. Consultation with David Fischer, Armstrong Services engineer, 1996.

6. Armstrong International, 1990. *Rohm and Haas Tames Energy Costs With Ongoing Commitment to Steam Trap Inspection*. Trap Magazine, vol. 58, no. 3, pp. 2-6.

7. U.S. Department of Energy. April 1998 *The Challenge: Improving Steam Turbine Performance at a Steel Mill*. 4 pp.

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Federal Energy Efficiency: An Analysis of Marketing Opportunities

Christopher Russell, Alliance to Save Energy, December 30, 1999

Executive Summary

Energy efficiency emerges as a management priority for federal facility managers in the wake of the White House's Executive Order 13123, issued on June 3, 1999 (Federal Register, June 8, 1999).[1] The spirit of this E.O. is consistent with the Administration's proactive policy stance with respect to energy conservation, atmospheric pollution control, and global climate change mitigation. Over 500,000 buildings, representing $3.5 billion in annual energy expenditures, fall within the scope of accountability established by this E.O. Implications are several-fold. First, the E.O. recognizes that federal facilities, in total, present an enormous opportunity to positively impact environmental improvement goals, all within the purview of one management directive. Second, the national dispersion of federal facilities means that each facility is potentially a showcase for energy management technologies and practices that can be emulated by surrounding communities. Finally, the E.O. opens marketing opportunities for suppliers of energy efficiency solutions, in the form of products, services, and consulting expertise. Vendor opportunities encompass technical issues as well as management training and program promotion within agencies.

Introduction

The purposes of this paper are to provide a concise introduction to Executive Order 13123; outline the goals, organization, and timetables involved in implementing that order; and describe marketing opportunities that the executive order creates.

Goals of the Executive Order

The overall goal of E.O. 13123 is to increase energy reduction goals, accountability, and procedures for ensuring efficient use of energy on federal facilities. Such practices are broadly applicable to facility management, facility design, and procurement. Accountability is implemented through the budgeting process, and progress is monitored through a scoring system. The E.O. explicitly recognizes that third-party energy service contracting will be integral to the achievement of most goals. Superior gains in efficiency will be recognized by giving awards to top performing agencies.

Quantitative energy efficiency goals apply to each individual agency, as opposed to applying in total to all agencies. Note that base years from which achievements are to be measured are sometimes as far back as 1985; this is done largely to recognize and incorporate efficiency gains that have been achieved due to earlier management initiatives. In all instances, the E.O. stipulates that the cost effectiveness of energy management implementation be measured with life-cycle[2] cost measures. (Table 1 outlines the quantitative goals called for by E.O. 13123.)

A couple of points emerge. Agencies are encouraged to aggregate their utility purchasing needs so that they may command greater purchasing power in bulk energy commodity markets. Meanwhile, emphasis on renewable energies and energy management practices gives new and probably unfamiliar responsibilities to federal facility managers. Accordingly, the opportunities for third-party energy services companies to provide consultation and performance contracts are unmistakable.

Federal Organization

Implementation of E.O. 13123 involves not just end-use facilities, but overall coordination among the Department of Energy (and its subordinate Federal Energy Management Program) and the Office of Management and Budget. Congress and the Office of the President review periodic progress reports. Vendors that pursue

[1] The full text of the executive order is available at http://www.pub.whitehouse.gov/uri-res/i2r?urn:pdi://oma.eop.gov.us/1999/6/4/6.text.1

[2] Life-cycle cost accounting for implementing any efficiency measure includes contract development and vendor search costs, acquisition and installation, financing costs, the sum of annual operating costs (including fuel) over the expected life of the asset, and periodic maintenance and/or overhaul costs. In some cases, costs may be offset by the residual (scrap or salvage) value of assets that bear some market value upon disposal.

federal energy management opportunities will interface with facility managers, but knowledge of interagency interactions should help vendors as they shape contractual solutions.

The major components of E.O. 13123 implementation are:

2) **Budgets**. OMB offers guidelines for how agencies will develop annual budgets that adequately address energy efficiency implementation and goals.

3) **Implementation plans**. Each agency is responsible for the submission of an annual action plan that outlines tasks intended to achieve the E.O.'s goals.

4) **Technical assistance**. OMB, DOE, and FEMP are positioned to offer technical advice to facility managers.

5) **Annual Reports to the President.** Agencies report their annual progress toward compliance.

6) **Scorecards**. DOE and OMB cooperate in the development of scorecards for evaluating individual agency's compliance efforts. Scoring considers use of energy performance contracts, Energy Star® and other certified energy efficient products, renewable energy technology selection, metrics that specifically capture impacts of energy efficiency and greenhouse gas production, and any other innovative energy efficiency practices.

7) **Recognition and awards**. DOE may nominate specific agencies' energy management teams for outstanding achievements toward the energy efficiency goals. The Deputy Director for management of OMB will select from among those nominees the teams that will win a Presidential award for energy efficiency.

The key managerial structures that implement the Executive Order are as follows (see Figure 1).

Senior Agency Official (for each federal agency): This designation, which originates with this E.O., is given to an Assistant Secretary (or above) in each agency. This person maintains ultimate responsibility for implementation of this E.O. within that agency. Duties include annual reporting.

TABLE 1: ENERGY EFFICIENCY ATTAINMENT GOALS FOR INDIVIDUAL AGENCIES, PER EXECUTIVE ORDER 13123

Item	Discussion
Greenhouse gas reductions	Reduce by the year 2010 to a level 30 percent below 1990 emissions.
Energy consumption per facility gross square foot	Achieve 30 percent reduction by 2005 and 35 percent reduction by 2010, compared to 1985 levels.
Industrial and laboratory facilities	Energy consumption improvements are to be measured per unit of production (or other units as applicable). Twenty percent reductions are to be achieved by 2005 and 25 percent by 2010, relative to 1990 as the base year.
Renewable energy usage	All facilities are encouraged to implement applications powered by renewable energy sources or by electricity that is generated from renewable energy sources.
Petroleum usage	Petroleum use is specifically discouraged, due to the greenhouse gas-intensive nature of petroleum combustion emissions. Natural gas and renewable energy sources are specifically cited as appropriate alternatives.
Source energy criteria	The E.O. recognizes total energy efficiency criteria for determining most fuel-efficient options. This is to compensate for efficiency distortions attributable to efficiency measurements that consider only the end-use application itself while ignoring the efficiency losses incurred during fuel extraction, conversion, and distribution to the end-use site.
Water conservation	Goals are pending a determination to be issued by the Secretary of Energy on or before June 8, 2000.

Technical Support Teams: These "agency energy teams," one for each agency, are comprised of selected staff within the agency. The team brings together procurement, legal, budget, management, and technical expertise. The team ultimately provides advice and guidance toward fulfilling the directions of the E.O.

Public/Private Advisory Committee: Individuals from private industry, the public sector, energy interest groups, and consumer organizations are hand-picked by the Secretary of Energy to serve on this committee. The committee generates advice on the selection and implementation of energy efficiency products and programs.

General Services Administration (GSA): This federal agency has broad property management responsibility for the federal government. The Executive Order states that GSA shall be responsible for "working with agencies" in their efforts to fulfill this energy efficiency directive. More immediately, GSA is expected to highlight in its product catalogs Energy Star® and similarly-designated energy efficient products. The Defense Logistics Agency (DLA) performs a similar role for facilities under the jurisdiction of the Department of Defense.

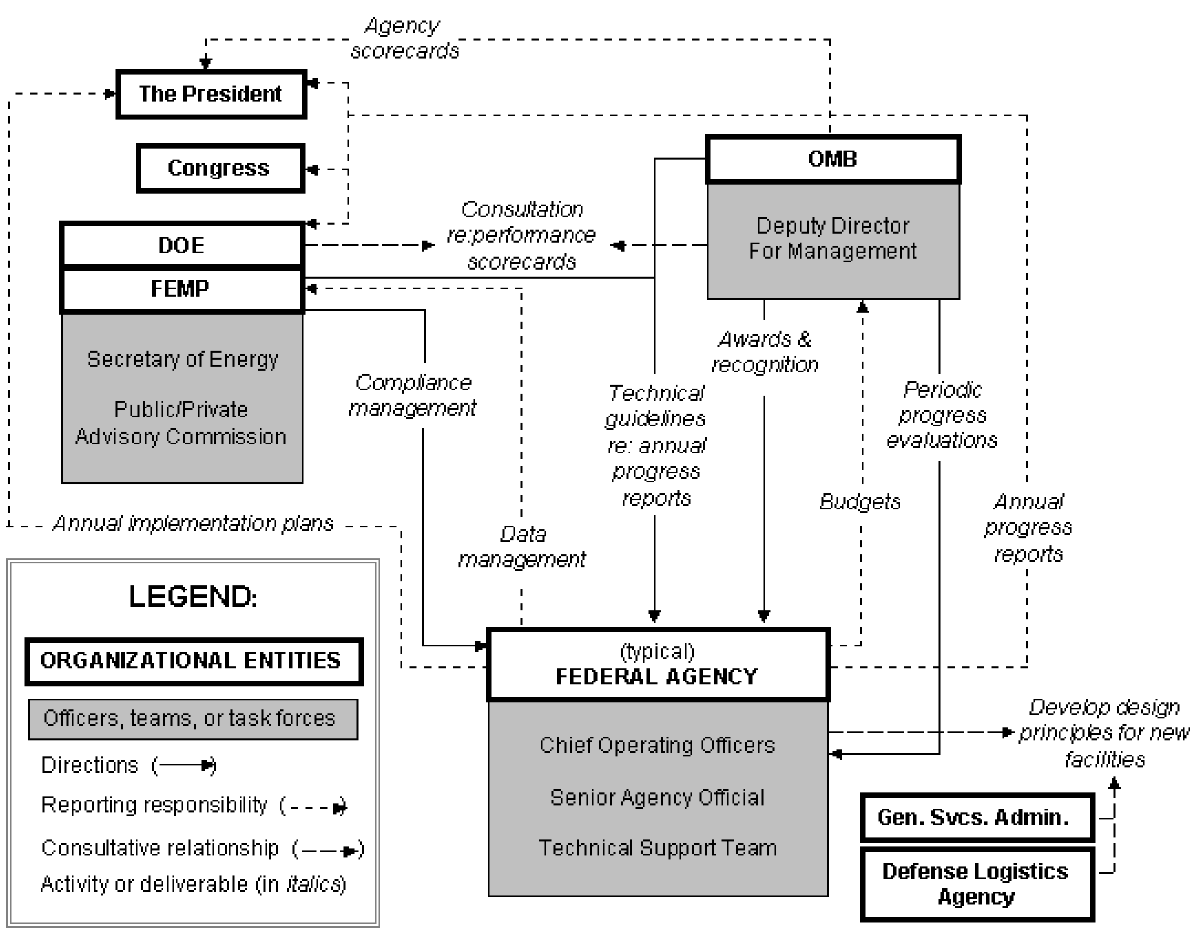
Defense Logistics Agency (DLA): This organization performs property management duties for Department of Defense facilities similar to the functions performed by GSA on behalf of civilian federal facilities.

Specific Opportunities

To comply with this Executive Order, federal agencies are tasked with a number of activities that are outside of their traditional scope of expertise. Accordingly, agencies will look to third-party vendors to acquire services and products. This list reviews the most probable opportunities for federal contracting:

1) **Energy saving performance and utility energy-efficiency service contracts.** This refers to contracted energy services that

FIGURE 1: PARTICIPANTS AND RESPONSIBILITIES, EXECUTIVE ORDER 13123



represent more than the simple purchase of utility power, gas, water, and other inputs. Energy performance contracts are available from energy service companies (ESCOs) in those states where permitted by utility regulatory commissions. Utility companies sometimes offer similar energy-efficiency service contracts (again, as permitted by state regulatory authorities). These services may take several forms:

a. **Energy service agreements.** A contractual arrangement for implementing energy conservation measures that often relieves the agency of high-impact, up-front costs. The vendor may retain title to the mechanical equipment, thus keeping responsibility for its upkeep and maintenance. In return, the agency pays a monthly service fee in addition to the expenses incurred for on-site energy consumption.

b. **Shared savings.** This variation on energy service agreements gives the vendor a pre-determined percentage of the savings that are attributable to their efficiency implementation efforts.

c. **Third-party financing.** Yet another variation on energy service arrangements entails implementation of major, new mechanical systems as financed by a third-party lender. In this instance, title to the equipment is maintained by a lender who finances the hardware selected by an energy service vendor.

d. **Facility energy audits.** Vendors may simply perform a pre-implementation diagnostic role. Audits can be arranged for a number of dimensions, including energy efficiency, emissions profiling, indoor air quality, water consumption. Audit findings lay the ground work for eventual implementation decisions. They also are necessary for determining the effectiveness of measures after they are implemented. Audits will document agency compliance with the E.O.'s directives and become the basis for eventual recognition and awards for accomplishments.

e. **Architectural & engineering specification opportunities.** The Executive Order directs that new facilities that are in the design and construction phase shall incorporate sustainable design principles. This means that energy efficiency criteria are systematically identified and incorporated in facility design, renovation, and construction. These criteria should demonstrate financial Sustainable design principles (construction, life-cycle costs, decommissioning).

2) **Financial analysis.** Implementation of energy efficient hardware—especially major mechanical systems—will require the financial analysis of different options. Life-cycle costing and rate-of-return analysis will be integrated with each engineering option.

3) **Legal support.** Federal agencies' legal staffs may seek assistance with the drafting of model lease provisions and build-to-suit lease specifications. Legal advice may also concern contract solicitation and bid review assistance.

4) **Engineering support.** Federal facility energy system requirements vary widely with building scale and purpose. Opportunities for consulting engineers include support for heating, ventilation, air conditioning (HVAC) systems as well as industrial & large-scale mechanical systems efficiency and emissions control. Steam, compressed air, motors, combined heat, cooling, and power are major end-use technologies that are prominent features of federal energy utilization. Consulting opportunities are also related to the Executive Order's encouragement of facilities to use renewable energy sources (biomass, bioenergy, geothermal, and others). Also, emerging efficient technologies are encouraged where practical. These include off-grid generation systems, including solar power, wind turbines, and fuel cells.

5) **Training and education.** Executive Order 13123 has implications for management behavior and organization as well as for engineering and facility management. Planning, monitoring, and reporting are all responsibilities that key officials and their staffs must absorb. These personnel may seek training and management coaching commensurate with these tasks.

6) **Program marketing.** Federal agencies' efforts to comply with the E.O. will necessarily include communications outreach within each facility. Program marketing internal to each agency should raise staff awareness of the E.O.'s objectives. The effort should also encompass training with respect to purchasing practices and the ac-

commodation of new technologies and their potential impact on the work environment.

Marketing to Federal Facility Managers

Individual federal agencies typically maintain a headquarters office in Washington D.C. along with regional offices located across the U.S and its territories. A large proportion of regional offices are leased through private property management companies. Often, several federal regional offices are housed in one building. Table 2 shows the regional breakdown of federal facilities.

As with any other marketing opportunity, the GSA-managed federal facility energy market can be approached through segmentation analysis. "Segmentation analysis" is a marketing process that businesses perform in order to estimate the potential number of customers for a product. It also delineates those customers into groups as defined by their motivation to buy. This exercise helps marketing staff to identify best customer prospects and to prioritize marketing resources accordingly.

Energy service companies (ESCOs) may employ a segmentation scheme to understand, codify, and prioritize the opportunities made available by E.O. 13123. Segmentation may be accomplished along one (or a combination) of several dimensions. These may be, for example:

1) **Location**. Geographic clusters of facilities that coincide with the multi-state regions would be a natural segmentation scheme for ESCO marketers.
2) **Energy use profile**. While the majority of government floorspace can be characterized as "office" use, attention must also be given to a variety of other facilities devoted to laboratory, health care, educational, correctional, warehousing, and other uses. ESCOs with particular expertise with certain end-use applications may segment the market accordingly.

TABLE 2: REGIONAL BREAKDOWN OF FEDERAL FACILITIES AS MANAGED BY THE GENERAL SERVICES ADMINISTRATION

Region	States/Territories Included	Number of Bldgs. Owned	Number of Locations Leased	Number of Agencies Served	Number of Employees Housed
New England	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	94	250	32	36,224
Northeast & Caribbean	New York, New Jersey, Puerto Rico, U.S. Virgin Islands	109	450	43	72,286
Mid-Atlantic	Delaware, Maryland, Pennsylvania, Southern New Jersey, Virginia, West Virginia	184	563	153	103,961
Southeast Sunbelt	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee	173	1,111	45	126,884
Great Lakes	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	195	801	107	97,727
The Heartland	Iowa, Kansas, Missouri, Nebraska	94	301	50	59,000
Greater Southwest	Arkansas, Louisiana, New Mexico, Oklahoma, Texas	378	736	38	94,287
Rocky Mountains	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming	248	375	27	45,209
Pacific Rim	Arizona, California, Guam, Hawaii, Nevada, Pacific Trust Territories, American Samoa, U.S. installations in the far east	177	904	45	95,000
Northwest/ Arctic	Alaska, Idaho, Oregon, Washington	119	381	131	35,000
National Capital	Washington DC and metropolitan area	194	470	91	389,489

SOURCE: GSA 1998 Annual Report

3) **Motivation of management**. Even within the market segment broadly defined as "office space," ESCO marketers should be able to further segment the market in ways that reflect management *motivation* or *disposition* toward energy efficiency. While the criteria for energy efficiency are largely imposed through the E.O., there will still be room for individual agency interpretation and application of the directives. These examples will better illustrate the point:

   a. Economic focus: management seeks solutions that provide the lowest demonstrable cost, consistent with the life-cycle cost principles discussed above.

   b. Budget focus: preferred solutions are those that minimize the impact on this year's capital or operating budgets.

   c. "Green" or environmental focus: management may prefer solutions that represent a visible demonstration of the agency's devotion to environmental concerns. In effect, the implementation of energy efficiency solutions becomes a fact that is incorporated in the agency's public image and communications.

   d. Workplace focus: in some instances, agencies will balance (or perhaps compromise) energy efficiency mandates with other management concerns. Competing issues may force managers to settle for energy solutions that are otherwise suboptimal.

   e. Technology focus: the hardware aspects of energy efficiency will appeal to certain agencies, especially those that have a technology focus in their mandate. It may be that such agencies are predisposed to favoring cutting-edge technologies from the available options.

Consider this additional note on the "motivational" segmentation scheme. The tenure of decision-makers may play a role in their selections. For instance, the manager with a short-term horizon for accountability may prefer a solution that maximizes short-term benefits. This manager would possibly discount options that offer greater total impacts over future years. This underscores the need for ESCO marketers to understand and accommodate the management environment in each client agency, especially defense agencies where uniformed personnel rotate frequently.

CONCLUSION

President Clinton's Executive Order 13123 challenges the federal government to become a practical example for achieving energy efficiency and emissions abatement. With over 280 million square feet located throughout the U.S. and its territories, federal facilities are poised to make contributions to the energy efficiency agenda. This is true not only for the sheer volume of energy consumed by federal facilities in total, but because of the integration of these facilities into local communities across the country. Installations include office, laboratory, warehousing, and industrial facilities. Indeed, federal facilities may become models of energy management for surrounding observers.

The comprehensive challenges embodied in E.O. 13123 will stretch the resources of federal facility managers. Accordingly, there will be opportunities for vendors to provide services that assist most agencies in reaching their energy conservation and emissions abatement goals. Energy performance contracts, engineering and legal advice, and in-house training and program awareness promotion are all federal needs to which prospective vendors may respond.

The implementation of this E.O. involves assignment of specific responsibilities to federal officials and task forces. This paper provided an overview of those management and organizational roles. Energy services and related vendors may refer to this portion of the paper to identify and understand the key decision-makers and the motivations that shape their receptiveness to vendor services.

REFERENCES

Additional details on the program elements described in this paper are as follows:

1. The full text to Executive Order 13123: http://www.pub.whitehouse.gov/uri-res/i2r?urn:pdi://oma.eop.gov.us/1999/6/4/6.text.1

2. The U.S. EPA Energy Star program and its procurement guidelines: http://www.epa.gov/energystar/

3. The General Services Administration's energy management information center: http://www.gsa.gov/pbs/centers/energy/default.htm

Steam System Optimization

Bob Aegerter, Equistar Chemicals, L.P.

Abstract

Most plant steam systems are complex systems. Usually the fuel required to produce the steam represents a major expense for manufacturing facilities. By properly operating and maintaining the steam system and making minor improvements, significant savings can be realized.

Savings Opportunities

Using today's energy costs, the incremental cost of generating a 1,000 lb./hr. of steam is typically \$25,000 - \$35,000/year. Numerous opportunities may exist in your plant to save several thousand pounds per hour of steam for little or no cost. After several of these projects are implemented, the total savings can be significant.

Develop a Steam Balance

To be able to optimize the steam system, you must be able to understand the system. Developing an accurate steam balance of actual operating conditions is an excellent tool for understanding your steam system. When developing the steam balance, special attention should be made to accurately measuring steam flows through steam let down stations and atmospheric vents for both summer and winter operating conditions. Understanding and controlling the steam let down and vent flows is essential to optimizing a steam system. The more accurate and detailed that you make the steam balance, the more successful your plant will be in reducing its steam costs. Once a steam balance has been developed, opportunities for steam savings become apparent, and project savings can be quantified.

Steam Excess or Deficit

Typically a plant will be either venting excess low pressure steam or letting down steam to meet the low pressure steam demand. If your plant is large and has several operating areas with independent steam systems, then some areas of the plant may have an excess of low pressure steam and other areas have a deficit. To optimize a steam system, the plant must be integrated as much as possible so that one operating area's excess steam can eliminate the deficit of steam in another area. Reducing steam costs should be a continuous process of eliminating sources of excess low-pressure steam until a steam deficit exists and then implementing heat recovery projects to create a condition of excess low-pressure steam. Using the steam balance as the blue print, projects should be coordinated so that large amounts of steam are never vented. This process should continue as opportunities become available.

Eliminating Excess Steam

Steam is vented from a pressure control valve when the amount of steam that is entering the header is in excess of the amount of steam required to maintain the pressure controller's set point. Often plants that are experiencing excess steam first look at ways of utilizing the steam. This often requires capital expenditure. A better solution, which costs less and usually yields better savings, is to eliminate or reduce steam entering the steam header. If a steam balance has been developed, it is an excellent tool to identify the steam sources. Areas to first look for possible waste are steam turbines and steam let down stations.

The easiest solution to eliminating excess steam is to shut down steam turbines that exhaust into the header and start up the motor driven spare equipment. Often times this step will be enough to eliminate the venting. Although shutting down steam turbines is the easiest solution to eliminating excess low-pressure steam, it may not be the most cost-effective solution because an electric motor is now being operated. If the excess steam that is being vented to the atmosphere can be eliminated without shutting down steam turbines, then other solutions should be pursued. If the plant's electrical rate schedule includes heavy penalties to creating new peak demands, then setting new electrical peak demands should be considered when turbines are shut down and motors started up.

To eliminate the excess steam condition, all sources of steam that are contributing to the excess steam condition must be identified. The surplus steam may be from a higher-pressure steam header. One of the best places to start looking is at steam let down control valves. If a let down control valve is open from a higher pressure header and steam is being vented at a lower pressure level, then steam is at an excess at the higher steam pressure level and sources of steam supplying the higher steam pressure header must be investigated. If the steam let down control valves are closed and steam is being vented, then the let down valves may be leaking through contributing to the excess steam problem.

The older your steam let down control valves and the higher the differential pressure across the valves, the more likely the valves are leaking through.

It is not unusual for an old steam let down valve to leak 2-5 Mlb./hr. of steam. The easiest way to determine if the valve is leaking, is to isolate the control valve and then observe the steam vent to see if the vent flow decreases. If the let down control valve does leak, then the valve should be repaired or replaced. Replacing a leaking valve with a ANSI class V control valve can be justified over repairing a standard shut-off valve. Class V control valves seat much tighter and will have positive seat much longer than standard control valves. It is possible that a standard control valve will start to leak soon after it is installed.

Steam traps that discharge into a steam header should be checked for proper operation. Badly leaking steam traps can over pressure a steam header.

If let down valves are not contributing to the excess steam problem, steam turbines exhausting into that header should be examined. The hand valve positions on steam turbines should be initially examined. Hand valves are provided on steam turbines to provide additional horsepower. Typically the hand valves are opened up when the turbine is new and left open. Operating a steam turbine with the hand valves open, when the horsepower is not required, requires the turbine to use higher steam flows than required. Hand valves on turbines should first be checked to determine if they are open. If the hand valves are open, the valves should be closed while checking the turbine's speed. If the turbine is able to maintain operating speed after the hand valves are closed, then the hand valves should remain closed.

Hand valves should be operated in either the fully open or fully closed positions. They are not meant for throttling steam.

If the hand valves are closed, then the nozzle block pressure should be checked. If there is a pressure drop across the governor valve that is more than 10% of the steam inlet pressure, then the turbine is over designed and could be rerated to operate more efficiently. Usually this will require that a new nozzle block be installed. Rerating a steam turbine is relatively inexpensive and can be justified if the turbine is causing 1,000 lb./hr. of steam to vent to the atmosphere. The plant should work with the steam turbine's manufacturer to obtain a proper rerate of the turbine.

Although more expensive than rerating an existing turbine, it may be necessary to replace a steam turbine with a more efficient turbine or an electric motor driver to obtain the amount of steam flow reduction that is required. When replacing a steam turbine, efficiency should be the prime concern. Typically single-stage steam turbines operate most efficiently in the 5,000-6,000 rpm range. Most rotating equipment operates at either 1,800 or 3,600 rpm. To get the additional turbine efficiency that is desired, it maybe necessary to speed the turbine up with a gear box. The additional cost of purchasing and installing the gearbox can be justified with the reduced steam flow through the turbine.

Another option to replacing a steam turbine that drives a fan or horizontally split case pump, is to extend the shaft on both ends of the driven equipment and have a motor driver and a steam turbine installed on opposite ends of the driven equipment. Either the motor or the turbine can easily be selected as the main driver by increasing or decreasing the speed of the steam turbine above or below the synchronous speed of the motor. If the turbine is operating at above the synchronous speed of the motor, the turbine will be carrying the load. If the turbine's governor is set to operate at below the synchronous speed of the motor, then the load will be transferred to the motor driver. This type of installation will add flexibility to controlling the steam balance.

Varying steam header pressures can affect the steam rate through turbines. If lower turbine steam rates are desired, then either the inlet steam pressure can be increased or the exhaust pressure decreased. Lowering the exhaust pressure will have more impact on turbine steam rates than raising the inlet pressure. The same technique can also be used to obtain more horsepower from a steam turbine that has a fully open governor valve.

Varying steam header pressures can also help transport steam between battery limits, which can help eliminate excess steam conditions. When steam headers are too small, varying the steam header pressures is an effective alternative to installing larger or parallel steam headers. The best way to determine the amount of variation available in your steam headers is to conduct a test. The steam header pressures should be adjusted by only 1-2 psi for each stage of the test and then left for a couple of days to determine the effect. If no problems are experienced, the test should be continued until the bottlenecks are identified.

If it is not possible to eliminate excess low-pressure steam, then effectively utilizing the steam is the next best alternative. Your boiler area's deaerator offers the opportunity to recover excess low-pressure steam at very low cost. If your deaerator is rated for a much higher pressure than it is operating, the deaerator pressure can be increased and more steam will be absorbed into the deaerator. The resulting hotter boiler feed water will reduce the amount of fuel required in boilers and will increase the amount of steam generated in waste heat boilers. Since most deaeartors operate at pressures lower than their maximum allowable design pressure, deaerators offer an opportunity for most plants to absorb excess steam.

Eliminating Steam Deficits

If steam is constantly being let down to meet the demands of the low-pressure steam header, then the steam header demands should be reduced. The first step is to eliminate condensate and steam leaks. Condensate and steam leaks should be repaired soon after they are detected because they can grow significantly larger in a very short time. If the leak cannot be isolated, several companies specialize in stopping steam leaks.

The plant's steam trap testing and repair program should be reviewed to determine its effectiveness. Questions that should be asked are the following:

1. How frequent are steam traps being tested?
2. What is the method of testing?
3. What is the steam trap failure rate?
4. What method is used to repair or replace the steam traps?
5. How long does it take after the faulty trap has been detected before it is replaced?

Too much emphasis has been placed on the manufacturer and type of steam traps used. There are numerous suppliers of quality steam traps. Standardizing on a specific trap that functions well in your plant, maintaining a good steam trap testing program, and repairing faulty steam traps soon after they are identified will minimize your steam trap energy costs.

Using the correct amount of steam for the required duty of equipment can significantly reduce your steam use. Too often controller set points are determined by "what we've always run before" and not what is most energy efficient. Over use of steam will usually cause more demand on cooling water systems or heat being lost to the atmosphere through fin-fan coolers or steam that is vented to the atmosphere. Using the plant steam balance and plant design information, the actual versus plant design steam use for all major steam users should be compared. If there are large discrepancies, in the amount of steam that is being used that cannot be accounted for by changes in plant operation, then there are savings opportunities.

Most plants can decrease their steam demand by having automatic steam control flow to the flare. Typically operators control the steam flow to the flare by manually adjusting a control valve based upon their observations of the flare tip. Many times that means using so much steam that the flame on the flare cannot be seen. A better way of controlling the steam flow is with a flare steam control monitor.

The flare steam control monitor uses an infrared detector to determine the amount of smoking at the flare tip and adjusts the steam flow to the flare to eliminate the smoking. The result should be that the flame at the flare tip should be visible and bright with no signs of smoking. Flare steam control monitors can usually be economically justified. If your flare has a flare control monitor, make sure the monitor is in control. If your flare doesn't have a flare control monitor, one should be installed.

Proper insulation of piping and equipment should never be overlooked to reduce the steam demand. Almost all plants that have been operating for several years have numerous insulation opportunities. Often flanges, control valves, steam turbines, man ways, sections of piping, heads on vessels, etc. are uninsulated. If steam is in demand at the steam pressure level of the uninsulated piping and equipment, then the piping and equipment should be insulated. An insulation survey should be conducted of the condensate and steam system and all uninsulated piping and equipment should be insulated. A study should also be conducted of all insulated high temperature piping that has been in service for numerous years. It may be economically justifiable to repair damaged insulation or add an additional layer of insulation.

If all of your steam users are efficiently using steam, then waste heat recovery opportunities need to be explored. The duties and temperature profiles on services that are cooled by air or water should be compared to services that are heated by steam. If the duties and temperature profiles compare favorably, consideration should be given to projects that would recover waste heat energy.

One excellent heat sink for waste heat recovery is deaerator make-up water. When the deaerator make-up water is preheated, then the deaerator's steam demand will be reduced. When installing deaerator make-up water preheat projects, the following hazards should be avoided:

1. When water that has not been deaerated is heated above a specific temperature, then oxygen will be released and corrosion in the carbon steel piping will occur. Your water treatment salesman should be consulted for the exact temperature. If your project will recover enough preheat to the deaerator make-up water that oxygen will be released, it will be necessary to install a stainless steel return system to the deaerator.
2. If the make-up water is heated too much and there is no stripping steam needed in the deaerator to maintain the set operating pressure, then good oxygen stripping will not occur in the deaerator. Your deaerator manufacturer should be consulted to determine the deaerator's minimum stripping steam requirements.

If after all opportunities for reducing the demand on all steam users have been exhausted and all economically attractive waste heat recovery projects have been implemented, steam is still being let down to meet the demands of a low pressure steam header, then consideration should be given to installing steam turbine drivers to replace electric motor drivers. Again, steam turbine efficiency needs to be a prime concern when installing any steam turbine.

Adding Flexibility

Steam systems are dynamic. Changes in the process can change the amount of steam that is venting to the atmosphere and being let down between pressure levels. Some flexibility needs to be built into the steam system to allow for these process changes. The following should be considered to add flexibility to your steam system:

1. Steam turbines and motor drivers should be identified that can be started up or shut down to minimize steam vents and let down flows.
2. Steam header pressures should be adjusted to allow steam to be transported to other locations or to reduce the steam flow through turbines.
3. The deaerator pressure should be varied slowly to eliminate steam venting but not to cause excessive steam being let down.

The above can be accomplished with good communications between operating areas, but advanced control schemes may be necessary to optimize the system.

Steam Boiler Optimization

Repairing steam leaks and insulating uninsulated equipment is also important at your steam boilers. Since boiler steam pressure and temperature levels are the highest in the plant, insulating piping and equipment and repairing steam leaks around the boilers will pay out very quickly.

Repairing air leaks around the boilers is also important. On negative draft boilers, air leaks waste fuel, cause refractory damage, and cause erroneous excess oxygen readings.

On positive draft boilers, air leaks waste fuel and can cause personnel injury. Some fan and boiler capacity are also lost with air leaks. Air leaks should be fixed at the first opportunity.

Damaged refractory offers energy saving opportunities because it causes hot spots on the outer shell of the boiler. The hot spots result in heat loss to the atmosphere and a reduction in boiler efficiency. Refractory damage can also lead to further mechanical damage to the boiler and possible personnel injury. Damaged refractory should also be repaired at the first opportunity.

Boilers need to be excess oxygen controlled. The oxygen analyzers should be calibrated and the fuel/air ratio controller tuned. Boiler excess oxygen levels should be controlled at the boiler manufacturer's recommendations.

Summary

This article is not meant to cover all the opportunities that are available in reducing your plant's steam costs, but as a guideline to how to approach reducing the costs. The key is understanding how your system operates and using that knowledge to make changes that will reduce your operating costs. Reducing your plant's steam costs should be a continuous process of eliminating sources of excess low pressure steam until a steam deficit exists and then implementing heat recovery projects to create a condition of excess low pressure steam. The steam balance should be your plant's blueprint to the sequence in which projects should be implemented. The plant steam balance should always be accurately maintained so that projects can be identified, as opportunities become available.

Industrial Insulation: An Energy Efficient Technology that Saves Money and Reduces Overall NOx Emissions
"A Case in Point with a Chemical Plant"

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Abstract

Increasing energy efficiency in U.S. industrial facilities is an important part of U.S. energy policy for attaining goals such as reduced greenhouse gas emissions, a stronger economy, and greater national security. One of the quickest ways to improve energy efficiency in the manufacturing sector is to install, upgrade and repair insulation on process piping systems and equipment. Insulation not only provides immediate reductions in greenhouse gasses by reducing energy consumption, but the dollars saved in terms of wasted energy are tremendous. The examples presented will quantify the possible reductions of specific greenhouse gases and will demonstrate that installing insulation results in major reductions in a facility's operating costs.

Overview

According to a U.S. Department of Energy (DOE) report, industrial and commercial facilities are currently responsible for about half of all U.S. energy consumption. As energy use increases, greenhouse gases such as Nitrogen Oxide (NOx) and Carbon Dioxide (CO2) are also increasing—a fact that has led to closer government scrutiny.

The EPA recently announced tighter emissions standards for NOx emissions from new electric utility and industrial boilers.The EPA lists NOx as an Ozone "precursor" and must be limited. The new revised limits will reduce the projected growth in NOx emissions by approximately 42 percent (45,800 tons annually) from levels that would have been allowed under current standards.

This type of regulatory action reflects the Administration's commitment to reducing greenhouse gas emissions to below 1990 levels by 2012. At the most recent Convention on Climate Change, the United States joined other countries in establishing binding targets and timetables for reductions in emissions of green-house gases. According to President Clinton, "Most of the technologies available for meeting this goal through market mechanisms are already out there."

Existing energy-efficient technologies, such as mineral wool insulations, are the most cost-effective way to reduce greenhouse gas emissions such as NOx and CO2. Unfortunately, such technologies are often over-looked and have been underutilized for decades. It is expected that the $6 billion in tax incentives included in the Clinton Administration's Plan to combat global warming will greatly accelerate the adoption of these technologies in the next several years.

Computer Program Quantifies Emissions, Energy Saved and Dollar Cost Savings

Insulation has always been "a good thing to do." Everyone knows it saves energy by preventing heat loss—but quantifying the savings has always been a difficult task.While everyone understands that insulation protects people from hot surfaces and that it prevents condensation, it is only recently that insulation has been thought of as a method for reducing greenhouse gas emissions. Again, the difficulty has been in quantifying the emissions saved for the insulation investment incurred.

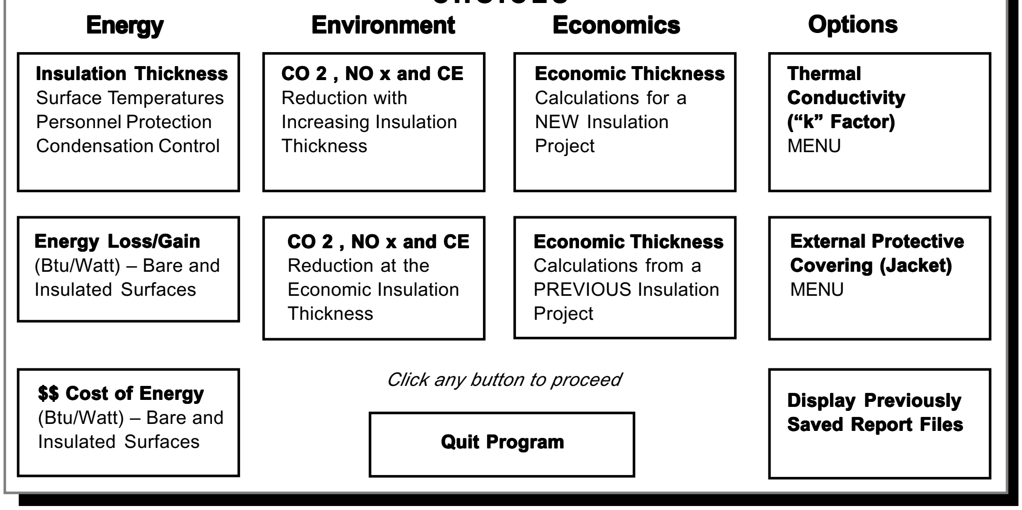
A new Windows® version of the 3E Plus computer software program (version 3.0) can now run these numbers for energy and environmental managers interested in making sound environmental/business decisions. The program is so successful it has been used by the DOE to develop its industrial insulation guidelines and is used as a tool in several DOE programs offered through its Office of Industrial Technologies. It is available free via the Internet at http://www.oit.doe.gov.

The new 3E Plus (version 3.0) program helps users calculate just how much insulation is necessary to reduce NOx, CO2 and Carbon Equivalent (CE) emissions; exactly how much energy is saved through applying a range of insulation thicknesses; and the dollar cost savings realized through preventing energy waste. With some fairly basic input information and the click of a button or two, maintenance managers, specifiers, building owners, insulation contractors, and energy and environmental managers can get valuable business and compliance data to help justify the insulation investment. (Figure 1 illustrates the kinds of calculating choices available to the user of the new 3E Plus program.)

Economics

What's made the decision to insulate difficult over the years is putting actual dollars to Btu loss. A major benefit of the new program is that it can convert energy to dollars to show how much is actually being saved. It can calculate the cost of bare and insulated surfaces per ft./year and the savings per ft./year as compared to bare surface dollar savings.

FIGURE 1—3E PLUS PROGRAM AVAILABLE CALCULATING CHOICES



New Program Calculations

Energy

The 3E Plus software uses the latest formulas for calculating heat loss and heat gain which are based on the newly developed ASTM C680 calculations. Energy use and environmental impact assessments are truly a global issue. And, it's not too hard to imagine a world where energy use and environmental impact may be regulated in a global environment. The upgrades made to this program reflect this kind of progressive thinking. Via the Internet, 3E Plus is available to the world and lets users calculate insulation thickness in five reporting units that address both nominal pipe sizes and tubing sizes. Reporting units for piping, tubing and flat surfaces include: U.S. customary ASTM C585 dimensions, U.S. metric ASTM C585 dimensions, European metric dimensions, U.S. customary elastomeric dimensions, and U.S. and European metric elastomeric dimensions.

Environment

The 3E Plus program makes it possible to calculate the savings in CO2, NOx and CE emissions that will result from using certain insulation thicknesses.The program demonstrates that by not using energy through the use of insulation you are not burning the extra fuel which contains these gases. Now that NOx is strictly regulated, energy and environmental managers are obliged to know just how much NOx they are emitting. The ability to calculate NOx emissions is an important addition to the program.

How One Company Used 3E Plus to Quantify Overall Energy and Environmental Savings

What about the real world? One company that wanted to find out how much they could save was H.B. Fuller Company, headquartered in St. Paul, MN. H.B. Fuller Company is a worldwide manufacturer and marketer of adhesives, sealants, coatings, paints and other specialty chemical products, with manufacturing and sales operations in more than 38 countries and customers in more than 100 countries of North America, Latin America, Europe and the Asia/ Pacific region and fiscal 1998 sales of $1.347 billion.The company was aware of how their costs were influenced by the amount of energy used in their manufacturing processes. They were also concerned about their plants' impact on the environment in terms of emissions.

H.B. Fuller decided to do an insulation energy appraisal of three of the company's Adhesive, Sealant and Coatings (ASC) plants in the Atlanta, GA, area. They wanted to determine (a) how much energy their mechanical insulation really saves, (b) if the installed mechanical insulation is performing adequately, and (c) if each plant's energy usage and emissions could be reduced with more insulation.

"When we received the detailed insulation appraisal reports for each location we were pleasantly surprised. In two of the three locations studied, the assessments were very positive, showing that the insulation already in place at these plants is in good shape and contributing significantly to energy savings. The insulation appraisal results for the Covington Plant showed that we have opportunities to save money if we installed and/or upgraded our insulation on some of the process piping and equipment. The type of information provided is exactly what is needed to find energy saving opportunities throughout H.B. Fuller Company."
Richard A. Rosvold, Advanced Engineer, H.B. Fuller Company

The three plants manufacture polymers, water-based adhesives and hot melt adhesives used in a variety of commercial and industrial products ranging from packaging materials, envelopes, appliances, book bindings, diapers, shoes, furniture, corrugated cartons and a host of others. Manufacturing requires heat in the form of steam and heat-transfer oil, distributed throughout each facility, in order to process and transport raw materials and finished products.

The Process

H.B. Fuller invited the National Insulation Association (NIA) to conduct the appraisal of the thermal industrial insulation performance for the piping, vessels, and equipment at their three Atlanta area plants—Covington Forest Park, and Tucker manufacturing facilities.

At each plant location, the facility engineers, plant managers, and/or the maintenace engineers were interviewed to determine the scope of the plant's energy usage and energy distribution systems. The appraisers inventoried each heated system in square or lineal feet, separeated by process temperature, pipe size, insulation type (thickness, outerjacket/lagging), operational hours, average ambient air temperature, and wind speed if exposed to the elements.

Energy Appraisal Results

The 3E Plus program calculated the input data from the appraisers and produced the results shown in Tables I, II, and III. These tables show savings in terms of Btu(s), Dollars, and Emissions for each of the three plant locations. They also show combined savings in terms of Btu(s), Dollars, and Emissions for all three ASC plants.

Before examining the data from the two other H.B. Fuller plants, let's follow through on the Covington location data.

How Much is the Btu Loss—or Savings Worth?

Prior to the development of the 3E Plus program, it was difficult to equate Btu(s) to dollars. For example, reviewing the Covington plant data shows a 6.05 billion Btu savings potential. What does that really amount to in terms of dollars and cents?

The answer $42,078 is easily calculated with the 3E Plus program and is shown in Table II.

Emissions Savings (Via Insulation) Can Now Be Quantified

The 3E Plus program can actually take the calculations in Tables I and II one step further and indicate to the end user what the environmental implications of an insulation decision can be.

The data in Table III shows that H.B. Fuller's current installation on the inventoried lines in the Covington plant reduces CO_2 emissions by 540,076 pounds per year (27); NO_x emissions by 853 pounds per year (28) and greenhouse gas emissions by 147,287 pounds per year of operation (29).

H.B. Fuller—The Total Picture

As previously noted, the H.B. Fuller insulation energy appraisal actually included three of their manufacuring facilities in the Atlanta area. Data on the Covingotn plant has already been discussed in previous sections. The company's Tucker and Forest Park plants, as you can see from the data in the tables, also show excellent savings for well insulated systems.

The Tucker plant with 2" of insulation compared to bare piping can potentially save 40.09 billion Btu(s)(7) which equates to $239,207 saved per year (20). The last column on Figures 2 and 4 shows the potential energy and dollars savings possible by using the current insulation and adding 2” insulation to bare pipes. These potential savings are 0.08 billion Btu per year (8) and $1,788 per year (21), indicating that the plant is already well insulated. Table III shows that through good insulation practices the Tucker Plant has already reduced annual emissions of CO_2 by 7.5 million pounds, NO_x emissions by 16,010 pounds and CE gases by 2 million pounds.

The Forest Park plant with 2” of insulation compare to bare piping can potentially save 1.55 billion Btu(s) (9) which equates to $13,364 saved per year (22). The last column on Figures 3 and 5 show the potential energy and dollars savings possible by using the current insulation and adding 2” insulation to bare pipes. These potential savings are 0.05 billion Btu per year (10) and $261 per year (23), indicating that the plant is already well insulatied. Table III shows that through good insulation practices the Forest Park plant has already reduced annual emissions of CO_2 by 117,643 pounds, NO_x emissions by 252 pounds, an CE gas emissions by 32,083 pounds.

TABLE 1—ENERGY IN BTU(S) SAVINGS WITH THE USE OF INSULATION, PER YEAR OF OPERATION

Total Btu Loss, No Insulation	Total Btu Loss November 1998 Inventoried Insulation System	Total Btu Loss If Upgrade to Include All Pipes with 2” Insulation Thickness	Btu Savings November 1998 Insulation vs. No Insulation	Btu Savings Insulate All Piping to 2”+ Insulation Thickness	Btu Savings Current Insulation + Insulate All Bare Piping to 2” Insulation Thickness
Covington, GA					
6.69 Billion Btu[1]	3.77 Billion Btu[2]	0.64 Billion Btu[3]	2.92 Billion Btu[4]	6.05 Billion Btu[5]	3.13 Billion Btu[6]
Tucker, GA					
41.48 Billion Btu	1.45 Billion Btu	1.37 Billion Btu	40.01 Billion Btu	40.09 Billion Btu[7]	0.08 Billion Btu[8]
Forest Park, GA					
1.67 Billion Btu	0.17 Billion Btu	0.12 Billion Btu	1.50 Billion Btu	1.55 Billion Btu[9]	0.05 Billion Btu[10]
Total for 3 Plants					
49.82 Billion Btu	5.39 Billion Btu	11 2.13 Billion Btu	44.43 Billion Btu[12]	12 47.69 Billion Btu	3.26 Billion Btu[13]

How to Interpret Table 1

1. If the Covington plant had no insulation (all pipes were bare) on the inventoried items, the annual Btu loss would amount to 6.69 billion Btu per year.
2. Like most manufacturing facilities, there were some insulated systems in the Covington plant. Calculating their energy loss with existing insulation shows they were losing 3.77 billion Btu(s) per year.
3. The 3E Plus program calculated that if the Covington plant insulated or upgraded their systems so that all lines were insulated with 2^2 of insulation, they could reduce their Btu loss from 3.77 billion Btu(s) per year to 0.64 billion Btu(s) per year
4. Comparing the energy savings for the Covington plant with current insulation vs. no insulation at all (all bare piping) shows they are already saving 2.92 billion Btu per year.
5. Comparing the energy savings for the Covington plant if all piping were upgraded to 2^2+ of insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially 6.05 billion Btu(s) per year.
6. Comparing the energy savings for the Covington plant if all piping that was not currently insulated were upgraded to 2^2+ of insulation thickness shows they could potentially save 3.13 billion Btu per year.
7. Comparing the energy savings for the Tucker plant if all piping were upgraded to 2^2+ of insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially save 40.09 billion Btu per year.

8. Comparing the energy savings for the Tucker Park plant if all piping that was not currently insulated were upgraded to 2²+ insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially save 0.08 billion Btu per year.
9. Comparing the energy savings for the Forest Park plant if all piping were upgraded to 2²+ insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially save 1.55 billion Btu per year.
10. Comparing the energy savings for the Forest Park plant if all piping that was not currently insulated were upgraded to 2²+ of insulation thickness shows they could potentially save 0.05 billion Btu per year.
11. Total Btu loss for all 3 plants with current insulation
12. Total Btu savings for all 3 plants already being realized with current insulation compared with no insulation on any pipes.
13. Total Btu savings potential for all 3 plants by using current insulation and adding insulation to bare pipes.This represents the incremental savings due to new insulation.

TABLE 2—ENERGY IN DOLLARS SAVINGS WITH THE USE OF INSULATION, US$ PER YEAR OF OPERATION

Total $$$ Loss, No Insulation	Total $$$ Loss November 1998 Inventoried Insulation System	Total $$$ Loss If Upgrade to Include all Pipes with 2” Insulation Thickness	$$$ savings November 1998 Insulation vs. No Insulation	$$$ Savings Insulate All Piping to 2”+ Insulation Thickness	$$$ Savings Current Insulation + Insulate All Bare Piping to 2” Insulation Thickness
Covington, GA					
$48,737[14]	$27,949[15]	$4,658[16]	$18,788[17]	$42,078[18]	$23,290[19]
Tucker, GA					
$251,337	$13,918	$12,131	$237,419	$239,207[20]	$1,788[21]
Forest Park, GA					
$14,673	$1,570	$1,309	$13,103	$13,364[22]	$261[23]
Total for 3 Plants					
$312,747	$43,437[24]	$18,098	$269,310[25]	$294,649	$25,339[26]

How to Interpret Table 2

14. If the Covington plant had no insulation (all pipes were bare) on the inventoried items, the dollar amount the company would be losing each year would be $46,737.
15. The insulation already in place reduces the dollar loss to $27,949.
16. The 3E Plus program calculated that if the Covington plant insulated or upgraded their systems so that all lines were insulated with 2² of insulation, they could reduce their dollar loss to $4,658 per year.
17. Comparing the dollar savings for the Covington plant with current insulation vs. no insulation at all (all bare piping) shows they are already saving $18,788 per year.
18. Comparing the dollar savings for the Covington plant if all piping were upgraded to 2²+ of insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially save $42,078 per year.
19. Comparing the dollar savings for the Covington plant if all piping that was not currently insulated were upgraded to 2²+ of insulation thickness shows they could potentially save $23,290 per year.
20. Comparing the dollar savings for the Tucker plant if all piping were upgraded to 2²+ of insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially save $239,207 per year.
21. Comparing the dollar savings for the Tucker plant if all piping that was not currently

insulated were upgraded to 2²+ of insulation thickness shows they could potentially save $1,788 per year.

22. Comparing the dollar savings for the Forest Park plant if all piping were upgraded to 2²+ of insulation thickness from a baseline of no insulation at all (all bare piping) shows they could potentially save $13,364 per year.
23. Comparing the dollar savings for the Forest Park plant if all piping that was not currently insulated were upgraded to 2²+ of insulation thickness shows they could potentially save $261 Btu per year.
24. Total dollar loss for all 3 plants with current insulation
25. Total dollar savings potential for all 3 plants already being realized with current insulation compared with no insulation on any pipes.
26. Total dollar savings potential for all 3 plants by using current insulation and adding insulation to bare pipes.This represents the incremental savings due to new insulation.

TABLE 3—ENERGY IN CO_2 GASES, NO_x GASES, AND CE GASES SAVINGS (PRODUCTS OF COMBUSTION—EMISSIONS)

Plant Name	CO_2 Emission	NO_x Emissions	CE (Greenhouse)
Covington	540,076[27]	853[28]	147,287[29]
Tucker	7,466,536	16,010	2,036,333
Foster Park	117,643	252	32,083
Totals for 3 Plants	8,124,255	17,115	2,215,703

How to Interpret Table 3

27. Current insulation on the inventoried lines in the Covington plant reduces CO2 emission by 540,076 pounds per year
28. Current insulation on the inventoried lines in the Covington plant reduces NOx emissions by 853 pounds per year.
29. Current insulation on the inventoried lines in the Covington plant reduces green house gas emissions by 147,287 pounds per year.

Energy Appraisal Shows Tremendous Savings Potential

As you can see from analyzing the numbers for each of the plant locations, the savings can be tremendous. In fact, we've found that the 3E Plus program helps end users better understand the true dollar and performance value of an insulated process system.

The insulation energy appraisal was able to easily document and then quantify H.B. Fuller's current energy performance with existing insulation, and the potential energy performance should H.B. Fuller choose to implement the recommended insulation program.

The cost of doing nothing and losing 5.39 billion Btu(s) (11) per year or $43,437 (24) versus the cost of insulating to the recommended thickness beyond what is currently in place and saving an additional 3.26 billion Btu(s) (13) and $25,339 (26) annually is now an "operating management" decision in addition to a maintenance decision. Even without further action, 3E Plus shows H.B. Fuller that effective insulation has already resulted in annual savings of 44.43 billion Btu (12) and $269,310 (25). This information by itself shows the value of effective insulation and reinforces the need for effective insulation in future projects.

And, for H.B. Fuller's environmental Manager, the environmental value of the company's actions as shown by 3E Plus is that H.B. Fuller is already saving 8 million pounds of CO2 emissions, 17,115 pounds of NOx emissions (16) and 2.2 million pounds of greenhouse gas emissions annually because of good insulation practices.

CONCLUSION

A properly selected, specified, and installed thermal insulation system is an excellent investment with high returns. When compared to other conservation measures, the payback is very quick—usually less than 6 months—and the savings are tremendous in terms of reduced energy use, increased process efficiency and reduced greenhouse gases. Using the 3E Plus (version 3.0) program, energy and environmental managers can now calculate greenhouse gas emissions and put actual dollar savings to Btu losses. This kind of data is invaluable for companies like H.B. Fuller who are seeking to make sound business/environmental decisions about a technology that offers tremendous payback over the life of their facilities.

FIGURE 2—TUCKER ENERGY SAVINGS POTENTIAL

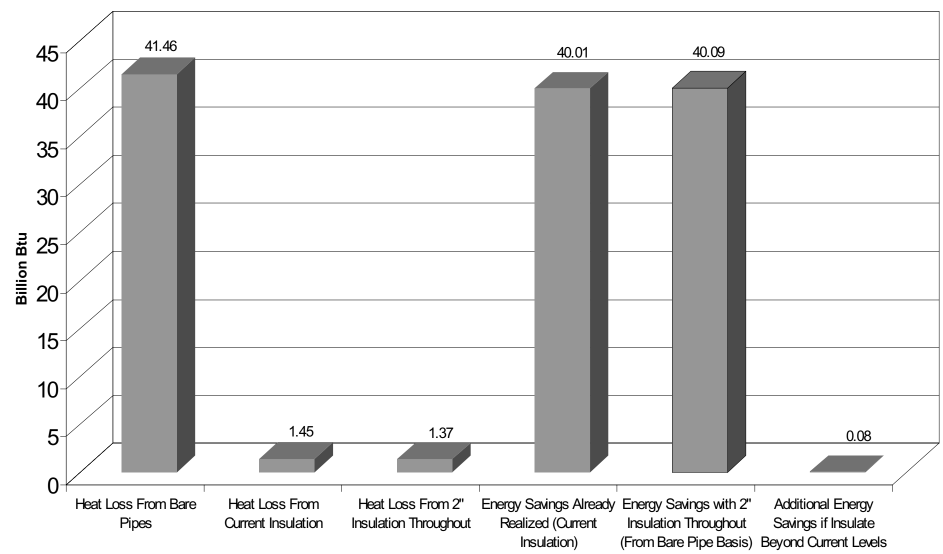


FIGURE 3—FOREST PARK ENERGY SAVINGS POTENTIAL

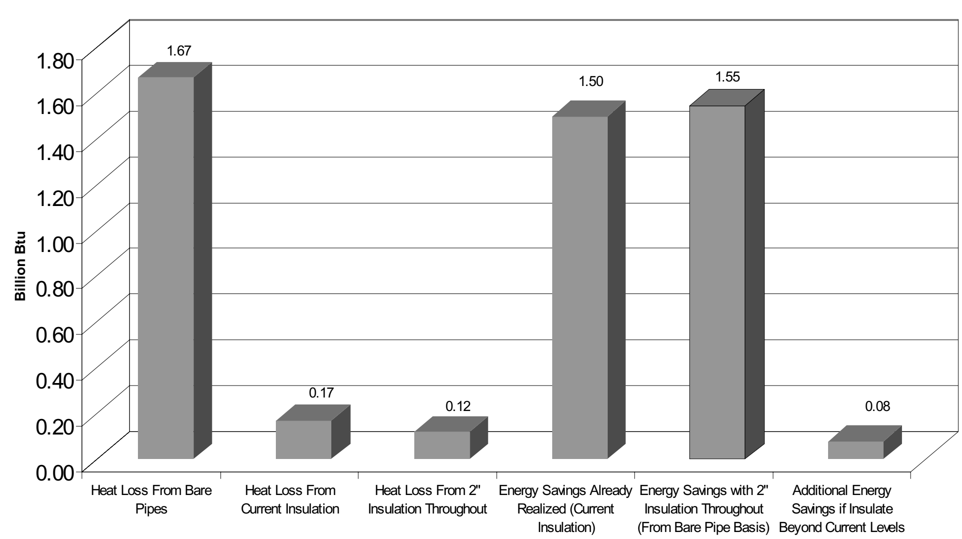


FIGURE 4—TUCKER DOLLAR SAVINGS POTENTIAL

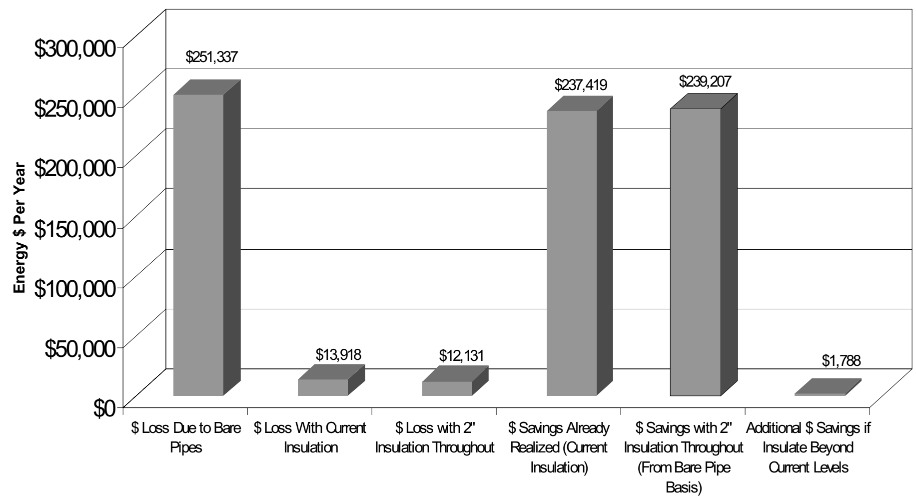
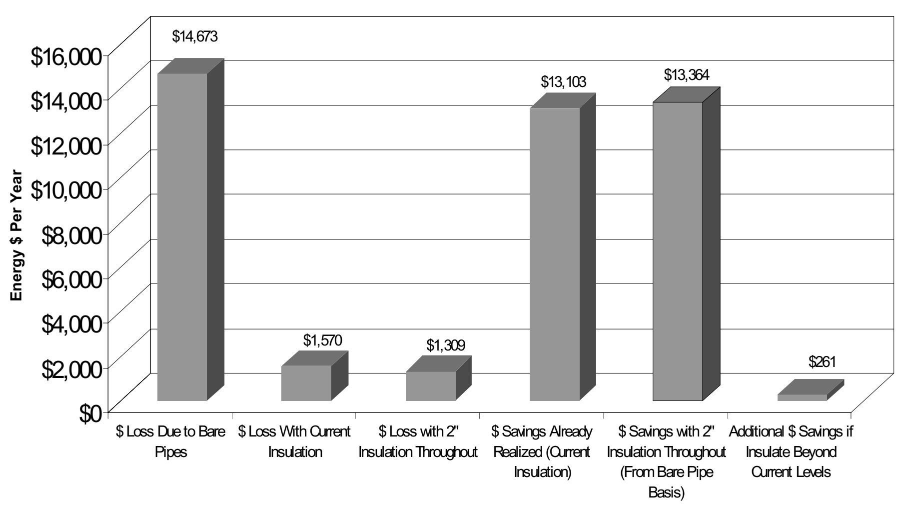


FIGURE 5—FOREST PARK DOLLAR SAVINGS POTENTIAL



Condensation Induced Waterhammer

By Wayne Kirsner, PE

Removing insulation from a live steam system is more hazardous than one might think. Sure there's the danger of being burned by brushing up against hot pipes—bare pipes carrying 100 psig[1] steam have a surface temperature of 334°F. But there's also a deadly peril that you, and the owner, engineer, or prime contractor might not understand—condensation induced waterhammer. Most people associate waterhammer with pipes clanging, like the banging often heard when old time steam radiators warm up. But these systems typically only use 2 psig steam. In this article, I'm talking about the type of waterhammer with enough force to kill people.

It's initiating mechanism is much different than the image most engineers and contractors have of what causes waterhammer (i.e. fast moving steam picking up a slug of condensate and hurling it downstream against an elbow or a valve). Condensation induced waterhammer can be 100 times more powerful than this type of waterhammer. It is initiated by the rapid condensation that occurs when steam is surrounded by subcooled condensate[2]—condensate that may have cooled because insulation was removed. Because it does not require flowing steam, condensation induced waterhammer often occurs during relatively quiescent periods when operators least expect it. It's most often initiated by opening a valve, even a drain valve to remove condensate. The overpressure from an event can easily exceed 1000 psi (pounds per square inch)—enough pressure to fracture a cast-iron valve, blow out a steam gasket, or burst an accordion type expansion joint. People asked to work on, or operate a live steam system need to understand this type of waterhammer so they know what they may be getting into. During my career as a forensic engineer, I've investigated two accidents where a lack of, or removal of insulation directly led to a waterhammer accident which either killed or maimed nearby workers. The following story is an example of one of those accidents.

A Startling Example

The steam pipe started to vibrate and shake. Don yelled at Clyde, "Let's get out of here...this thing's goin' to blow!" Clyde stuck his head out from beneath the steam pipe from where he was abating asbestos insulation. He heard a loud roar rumbling down the steam line like a freight train coming from the direction of the C-4 manhole. Don was already scurrying up the exit ladder. Clyde slid from beneath the maze of pipes and scrambled up the ladder behind Don, who was trying to break through the Visqueen plastic sheet that covered the manhole. It was sealed tight to prevent asbestos fibers from escaping. A white steam cloud rolled down the utilidor[3] from the direction of C-4 and began to flood the manhole. Another worker fleeing the encroaching steam crawled up behind them. Together they desperately tore through the stubborn Visqueen seal using a screwdriver to rip holes until it finally gave way, allowing them to shove open the steel hatch above and tumble out into the fresh air above. The swelling heat from the utilidor rose around them. There was pandemonium above the tunnel. Steam was billowing out of the C-4 manhole as well as the manhole they just exited. Fire engines were arriving. Men were shouting trying to figure out who among the insulator's crew was still down in the utilidor. Bobby and Wayne were missing.

Moments before the accident, Bobby, the insulation worker assigned to do the daily warm-up of the 2,200' steam main they were working on, had opened the 10" steam valve at manhole C-4 a second incremental turn. He noticed that oddly, the valve's handwheel spun freely. Just fifteen minutes earlier, he'd "cracked open" the 10" cast-iron valve to admit steam into the steam main to begin warming it up. He'd been energizing the G-line for three weeks now at the end of the insulator's shift and had never had the system warm up this quickly. It usually took from 30 to 45 minutes. When the valve's handwheel spun freely, he had been told the lack of friction meant that steam pressure on either side of the valve had equalized, so the warm-up was complete and he could open the valve the rest of the way. Bobby thought this warm-up seemed too quick and decided to check

[1]Psig denotes psi above nominal atmospheric pressure of 14.7psi

[2]Subcooled condensate is condensate that is cooler than the saturated steam temperature. So condensate at 300°F would be subcooled if it was in contact with 100psig steam which had a saturated steam temperature is 334°F.

[3]Shallow underground utility tunnels capped with removable concrete lids.

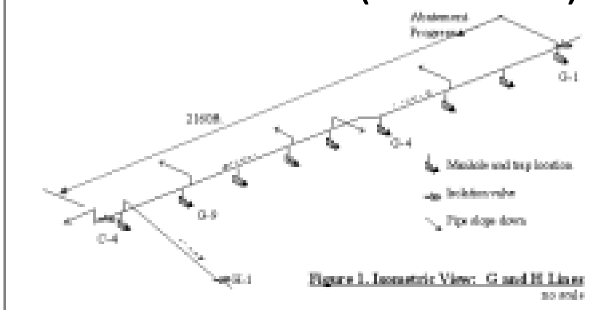
with his supervisor before spinning the valve open the rest of the way.

Bobby nudged past his co-worker, Wayne, as he made his way over to the material passout and yelled up through the plastic flaps to his boss, “She’s spinnin’ freely—is it okay to open her up all the way?” The supervisor was puzzled too. He had never been asked to operate a steam system before this job. “No,” came the muffled response through the plastic, “better continue to open her a little at a time like we were told to do.” It had been about a minute since Bobby had opened the valve beyond its initial first “crack.” As Bobby turned back to the valve, a “pop” was heard. Then a moment later, “KABOOM!” Hot water and steam exploded from the 10” valve. A white cloud of flashing condensate and steam filled the utilidor with a wave of heat. Wayne was knocked down and stunned by the initial blast of scalding water. The manhole exit was cut off by steam now spraying from the valve. The only way out appeared to be through the material passouts constructed into the roof of the utilidor. Bobby clambered up on top of the pipes, jumped up and caught his armpits above the opening. From there, he was able to hoist himself through the plastic covered opening. He emerged with some second degree burns, but was otherwise okay.

Wayne stumbled through the piping to the other material passout. Still stunned, his first jump was too weak and he fell back onto the piping, which by now was getting slippery from condensing steam. Air temperature in the utilidor was approaching 200°F. Wayne desperately collected himself. He thought that this might be his final chance to escape. He groped his way back up onto the slippery pipes, took a breath of the searing air, and leapt up again into the plastic covered opening. This time he was able to hook one elbow above the rim and, with his life on the line, kick up through the opening.

Clyde and Don saw Wayne crawl out through the plastic flaps of the material passout. Wayne rose to his feet and started screaming for help. His protective clothing was shredded, loose skin was sloughing off his exposed arms and legs. He was badly burned. Clyde yelled at passersby to call an ambulance as they ushered Wayne away from the steaming manholes. Soldiers with a knowledge of first aid rushed him to a barracks across the street and started to apply cold packs to his burns and give him cold drinks. Wayne’s throat was beginning to constrict. An ambulance arrived to rush him and Bobby to the hospital. As the injured workers were being cared for, Clyde turned his fury on his supervisor, “You stupid idiot, we told you this would happen.”

FIGURE 1. ISOMETRIC VIEW: G AND H LINES (NO SCALE)



WHAT HAPPENED

For four weeks asbestos workers had been removing asbestos insulation from the 2,200’ section of the steam main known as the G-Line and the 120’ H-Line. (See Figure 1.) Like all steam mains at Fort Wainwright, Alaska, the G- and H- Lines ran underground in narrow utilidors filled with pipe. Originally, the insulation subcontractor had been tasked with abating the steam main with the lines energized. This job proved to be nearly impossible for the workers. Utilidor temperatures reached 160°F as insulation was removed from the 325°F pipe carrying 80 psig steam. Laborers who had to be suited-up and masked to work in the asbestos-laden environment were dropping from the heat or quitting. After complaints from the insulators’ union hall, the prime mechanical contractor was forced to seek relief from the owner. A compromise was struck after the first week: steam would be de-energized at midnight before each workday; asbestos abators would start work at 4:00 a.m. and finish by noontime, at which time steam would be restored.

The prime contractor subsequently informed the insulation subcontractor that he would be responsible for de-energizing and re-energizing the steam line daily. (The subcontractor protested vehemently, but the prime contractor had no steam-fitters certified to enter an asbestos-laden atmosphere. If steam were to be shut-off, the abatement crew was directed to do it.) Two of the subcontractor’s men received about 45 minutes of training from the prime contractor’s QC (quality control) supervisor. Neither had any prior experience in operating a steam system. During the three weeks before the accident, the insulation contractor's men started up and shut down the steam system. By the beginning of the laborers' workday, temperatures in the utilidors were still around 120°F and despite frequent breaks to cool off and rehydrate, conditions were barely tolerable.

Unfortunately, the discomfort to the workers was not the only consequence of removing the insulation from active steam mains that had gone unforeseen. There was also the effect on the steam traps that remove condensate from the steam mains. At the system's normal operating conditions and with the main insulated, the traps had better than a seven to one safety factor for condensate removal. With the insulation removed, however, heat loss from the pipe increased almost 18 fold so that traps had less than one-half the capacity needed to keep up with the condensate that was being generated! This situation was not good. Condensate build-up in steam mains will lead to waterhammer, especially if the condensate is allowed to cool.

Abatement began at Manhole G-1 and headed south toward C-4 at the rate of about 125 feet per day. As abatement proceeded down the G-Line, local traps serving the uninsulated portion of the line were overwhelmed with condensate during the period the lines were energized each day. In the first two weeks, however, this didn't cause a problem. Excess condensate merely rolled down to C-4 on the south end and G-1 on the north end. Traps on the south end still serving insulated portions of the line had adequate capacity to remove the excess condensate. On the north end, the steam valve was left closed so trouble was avoided. After two weeks of daily start-ups without serious incident, the asbestos crew grew confident that start-up of the steam line was no big deal. By the beginning of the third week, insulation removal had reached Manhole G-9 near the south end of the long steam main. Calculations show that to this point, the rate of condensate being generated in the southern section of the G-Line began to exceed the net capacity of the traps to remove it. Condensate began to accumulate.

Condensate accumulation during steam operation can cause waterhammer. However, as long as condensate is religiously drained everyday before start-up, a catastrophic waterhammer accident might still be averted. The problem in this scenario was that condensate wasn't being drained religiously. The insulation workers given responsibility for energizing the steam main daily didn't fully appreciate the danger inherent in starting up a high-pressure steam system that contained condensate. They did not routinely open drain valves to bleed the system of excess condensate either at night, when they shut the system down, or at noontime, when they re-admitted steam through the C-4 valve to re-energize the steam main.

As the third week began, the severity and frequency of waterhammer began to accelerate. Residual condensate accumulated in the steam pipe at C-4 due not only to operation of the uninsulated steam main, but also due to condensate formed at start-up that went undrained. Moreover, the residual condensate cooled as it sat. Early in the third week, heavy banging forced abatement workers to evacuate the utilidor. Clyde, one of the more vocal workers, complained to the abatement supervisor, "This thing sounds like it's ready to explode. What are you going to do about it?" The supervisor advised the prime contractor who knew about the waterhammer since he'd also had men run out of the abated portion of the utilidor by the severity of the banging. Neither man however, understood what was happening in the steam mains. The action they took was to move Clyde to a different work area.

By Wednesday of the third week, all the insulation had been stripped from the steam main. By the next morning, the day of the accident, I calculate that enough condensate accumulated at C-4 to extend over 300 feet up the steam main. In addition, condensate accumulated in the 120' long H-Line perpendicular to the G-Line. Due to a design oversight, there was no drain or trap upstream of the gate valve at Manhole H-1. The prime contractor, not comprehending the pitch of the H-Line, did not realize that condensate would accumulate against the H-1 valve during the three weeks of on-off steam operation. Hence, the line filled with condensate as depicted in Figure 2.

FIGURE 2. H-LINE FULL OF CONDENSATE TO OVERFLOWING

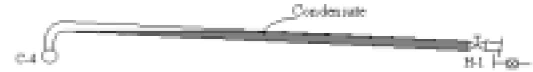
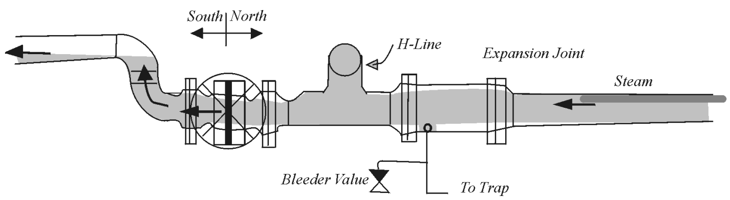


Figure 2. H-Line Full of Condensate to Overflowing

On the day of the accident, in order to isolate another steam main for repair work, the prime contractor decided to energize the G-Line early while the asbestos crew was still working. The asbestos crew was instructed to start up the G-line an hour and fifteen minutes before their quitting time. In addition, unbeknownst to the asbestos crew, the contractor's quality control supervisor decided to expedite warm-up of the steam main by admitting steam through the other steam isolation valve at G-1 at the far end of the G-Line. The G-1 valve was opened by the QC supervisor as much as 30 minutes before Bobby first cracked open the steam valve at C-4. The situation at the time, 15 minutes before the accident as Bobby readied to crack open the C-4 valve, is as shown in Figure 3. Subcooled condensate filled the steam line on both sides of the C-4 valve as well as completely filling the H-Line. High-pressure steam admitted through G-1 had pressurized the steam main and was sitting atop the condensate on the north side of C-4. The south side of the valve was also under steam pressure which, based on testimony, was probably slightly less than that on the north side.

FIGURE 3. CONDITIONS BEFORE BOBBY PREPARED TO OPEN THE C-4 VALVE



Now ask yourself, "If I were responsible for this job, would I have recognized this situation as dangerous? Some would answer, "Not necessarily—as long as there is no fast moving steam, there's no danger of waterhammer. Opening C-4 slowly and incrementally should prevent steam or condensate from moving quickly and thus prevent a waterhammer." While many knowledgeable steam people will tell you this, it's wrong—dead wrong. High-pressure steam in contact with subcooled condensate is dangerous. It's a recipe for condensation induced waterhammer.

Knowledgeable steam people might also suggest that by opening the C-4 bleeder valve to drain the condensate, the steam would push the condensate out. When the lines are emptied, you're in the clear. This reasoning is wrong too. Opening the condensate bleed valve in the situation above will trigger the accident. Neither the bleeder valve nor the steam valve can be opened without provoking an accident.

How can knowledgeable steam people be so wrong about what to do? The answer is that few of us understand the mechanism of condensation induced waterhammer.

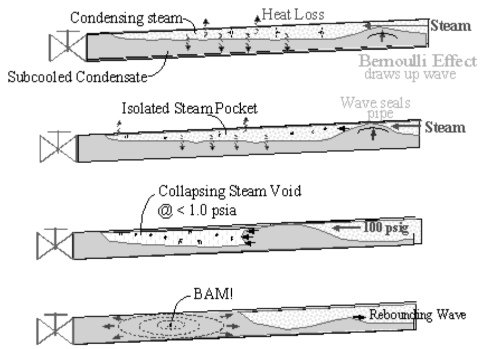
Condensation Induced Waterhammer

A condensation induced waterhammer is a rapid condensation event. It could also be aptly termed a "rapid steam bubble collapse." It occurs when a steam pocket becomes totally entrapped in subcooled condensate. As the steam gives up its heat to the surrounding condensate and pipe walls, steam changes from a vapor to a liquid state. As a liquid, the volume formerly occupied by the steam shrinks by a factor of several hundred to over a thousand times, depending on the saturated steam pressure.

Similarly, the pressure in the void drops to the saturated vapor pressure of the surrounding condensate. (For example, the saturated vapor pressure of condensate at 80°F is only .5 psia.) This condition leaves a low-pressure void in the space formerly occupied by the steam that the surrounding condensate, under steam pressure itself, will rush in to fill. The resulting collision of condensate generates an overpressurization that reverberates throughout the condensate filled portion of the pipe. How severe is the overpressurization? Remember that water is virtually incompressible. In a collision, it does not give. Think of the last time you did a belly flop off the low dive—the water felt pretty "stiff" didn't it?

The three factors which most influence the occurrence and severity of a condensation, induced waterhammer are: (1) the accumulation of condensate, (2) the steam pressure, and (3) the degree of condensate subcooling. If condensate has been allowed to fill a steam main to a depth of more than 20 percent of its diameter, steam pressure is high, and the condensate is subcooled more than 40°F, the overpressure resulting from an event can easily exceed 1000 psi. This is enough pressure to fracture a cast-iron valve, blow out a flange gasket, or burst an accordion type expansion joint. And, in fact, failure of each of these components in separate condensation induced waterhammer accidents has resulted in fatalities.

FIGURE 4. RAPID STREAM FLOW AND THE BERNOUILLI EFFECT



One might wonder at this point whether it is common for steam and condensate to come into contact in a steam system? Good design and operating practice aim to avoid mixing high pressure steam and excess condensate by making sure steam mains are properly trapped and live steam is kept out of condensate return systems. Nevertheless, it does happen. In steam lines, high-pressure steam can contact subcooled condensate when something goes wrong (e.g. when a trap assembly becomes plugged with scale causing a drip leg to fill with condensate). Why don't situations like this result in destructive condensation induced waterhammer more often? There are two reasons: if insulation keeps the condensate from cooling more than a few degrees below steam temperature, there is not enough subcooling for a waterhammer to develop; and, pipe geometry. A steam bubble must become entrapped in subcooled condensate for a collapse to occur. In a vertical pipe such as a drip leg where steam is above the condensate, it's difficult to entrap the steam because natural buoyancy tends to keep the two fluids separate[4]. In fact, research experiments show that it's difficult to entrap a steam void in any pipe sloped downward in the direction of steam flow more than ½" in 1". However, at slopes less than this level and in upwardly sloped pipes, it's a different story.

At Fort Wainwright, the pipe slope to C-4 is ¼" in 10'—normal for a steam line. Thus, the line is nearly horizontal. How does steam resting atop subcooled condensate in a nearly horizontal line become entrapped? The sequence outlined above in Figure 4 provides the explanation.

Steam residing over subcooled condensate loses heat to the condensate and the surrounding pipe, which causes the steam to condense. The continual loss of steam induces fresh steam to flow in to replace it. Rapid steam flow over condensate will tend to draw up a wave in the condensate through the Bernoulli effect.[5]

If the rate of heat transfer is rapid enough for a given condensate level, the induced steam velocity will draw up a wave high enough to seal the pipe.

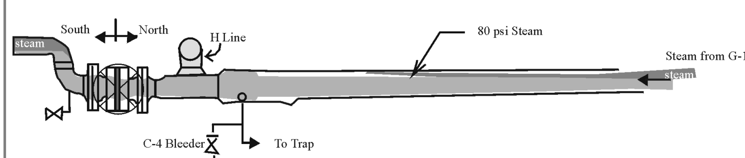
The creation of a seal immediately isolates the downstream steam pocket from the upstream supply creating a steam pocket. Ongoing condensation in the isolated steam pocket drops the pressure causing a slug to accelerate into the void.

The formation of a condensate seal is a necessary condition for a rapid condensation event in a horizontal line.

BACK AT THE ACCIDENT

Now, return to Manhole C-4 just before the accident. Bobby had opened the bleeder valve at C-4 (for the first time per a special instruction from the QC supervisor) and then proceeded to crack open the C-4 steam valve. Both of these actions presumably resulted in condensate draining from the system on the north side of the C-4 valve. The pipe volume vacated by the draining condensate at C-4 drew in steam

FIGURE 5. STEAM ENCROACHMENT AS CONDENSATE IS DRAINED



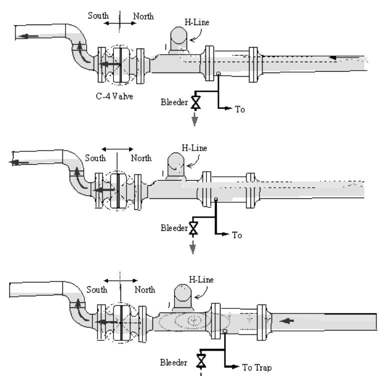
[4]A condensation induced waterhammer is possible if a vertical pipe is drained extremely fast.

[5]The Bernoulli effect describes the decrease in pressure (generally taken perpendicular to the direction of the flow) of a fluid as it speeds up while passing through a converging section. Potential energy (in the form of internal pressure) is thereby transferred to kinetic energy (in the form of fluid velocity).

along the top of the pipe from the north to replace it (Figure 5).

As the torrent of steam reached down the nearly horizontal line toward the vertical opening to the H-Line, the steam sought to flow up into the H-Line riser. It probably emitted a bubble of non-condensables into the H-Line and snapped back. The non-condensables tend to

FIGURE 6. THE PATH OF STEAM APPROACHING THE H-LINE



insulate the steam from the cooler condensate and pipe. In experiments that were run, this was the trigger necessary to set off the even. The next time the steam peaked around the vertical rise, the steam condensate interface shattered causing rapid condensation of the steam. The impulse of make-up steam flow pulled up a wave to trap the steam pocket. The entrapped steam pocket collapsed hard, drawing a slug of water from the north and crashing into the collapsing void faster than the eye could follow. The collision of the slug with the condensate at C-4 created an over pressurization that rebounded throughout the water filled portion of the system including up the H-Line where Clyde and Don would have been working. (See Figure 6.)

The overpressure of the waterhammer would have caused the double-elbow riser at C-4 to compress. The pipe and valve flanges twisted in response to the deflection of the double-elbow riser. The twisting flange caused the cast iron valve body to crack at the flange neck causing first condensate, then steam to spray from the valve.

Was This Accident Preventable?

Of course. Insulation should not have been removed from active steam lines without first checking the capacity of steam traps to handle the extra condensate load (a crucial factor rarely considered). Insulation workers should never have been tasked with warm-up of the steam mains. And nonessential workers should never be in a utilidor or manhole during start-up of a cold steam system. I could go on but here's what I want anyone who is going to work around a live steam system to know:

Don't get used to hearing waterhammer in a steam system. It's an indication something is wrong. If the space in which you must work is confined, the steam system should be shut down or isolated before you enter the space.

High pressure steam in contact with subcooled condensate is an unstable and potentially explosive mixture. A good recipe for the mixture is inoperative traps and uninsulated or deadened steam mains. When both of these conditions are met simultaneously, the system is not safe.

Don't admit steam into a line filled with subcooled condensate. In fact, always be wary of admitting steam into any cold steam line if you cannot be absolutely certain that the line's been completely drained.

If you suspect a pressurized steam line is filled with subcooled condensate, don't attempt to drain the condensate. Shut the steam off first, then drain the condensate.

A mixture of steam above subcooled condensate can sit dormant in an isolated steam line like a loaded gun awaiting a triggering event. Opening a valve to admit steam or opening a bleeder to drain condensate can trigger a rapid condensation event. Don't let yourself or those you supervise inadvertently pull that trigger.

Wayne Kirsner is a consulting engineer who investigates industrial steam accidents and troubleshoots large chilled water and steam distribution systems. He is a frequent contributor to HPAC (Heating/Piping/Air Conditioning) Engineering Magazine and the American Society of Heating, Refrigerating and Air Conditioning Engineers ASHRAE Journal. In addition to his work as a defense expert in steam accidents, he does training around the country on understanding and avoiding waterhammer. He is an ASHRAE Distinguished Lecturer. For more information and access to articles by Mr. Kirsner, see his web site at www.kirsner.org.